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ENERGY SOURCES AND POLICIES, THEIR IMPACT ON AIR POLLUTION, CURRENT AND PROJECTED

L. M. Sharpe

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L. M. Sharpe

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SUMMARY

Introduction

There have been a number of energy studies over the last 15 - 20 years that have attempted to project the national energy needs to various dates in the future. Rarely have they gone beyond the year 2000. The authors of some of these studies have been venturesome enough to predict the mix of energy fuels. None have made more that cursory attempts to deduce the atmospheric pollution burden derived from those projections.

This study compiles energy projections and the "mix" of energy sources to the year 2000, made as recently as 1967, and, on the basis of these data: estimates the atmospheric pollution burden to be expected by the years 1980 and 2000 provided present fuel policies remain essentially unchanged; summarizes some of the major technological developments that could have an impact on energy source selection and total energy requirements; identifies and discusses some of the major government policies that affect both fuel source and energy demand; outlines some approaches to an evaluation on a benefit/cost basis of alternative policies that would reduce atmospheric pollution; and completes the analysis for the solvent refined coal process.

Historical

A review of the historical energy data (1950 - 65) disclosed that the total energy demand increased faster than the population, probably as a result of an increase in the standard of living as well as per capita industrial productivity. The total demand would have been even greater were it not for a trend toward increased efficiency in energy production and utilization. Since World War II the use of coal has been decreasing but, by 1965, its use appears to have stabilized. In the same period the use of petroleum products had doubled while natural gas combustion demonstrated a spectacular increase - up by a factor of four. When the consumption of fuels is analyzed according to sector it is observed that (1) the use of coal decreased in the transportation, household and commercial, and industrial sectors while the utilities increased their demand for this fuel so that its consumption is expected to equal that of 1947 in the near future, (2) the use of natural gas rose most rapidly in the household and commercial sector although the industrial sector consumes the most, and (3) the petroleum products maintained their relative distribution among the various economic sectors with transportation taking the largest "bite."

The selection of energy source and its partition among the various economic sectors has been determined, up to the present, largely by inter-fossil fuel competition, consumer preference and regulatory policies.

Although natural gas was the source of more energy in 1965 than any other fuel, it contributed substantially less pollutants in the aggregate than low-boiling petroleum products, coal or fuel oil. The total contributed by the low-boiling fractions, notably gasoline, exceeded by a wide margin those originating from coal, the second highest contributor.

It is concluded that in order to deal effectively with a rapidly escalating air pollution problem, a much greater effort than is currently in force must be mounted by both government and industry without delay making maximum use of research resources, technological transfer and innovation.

Future Energy Requirements and Sources

In comparison with 1965, the energy requirements by 1980 and 2000 are expected to increase by 60% and 170% respectively while the population will have increased only by about 30% and 70%.

The integrated energy requirement for 1965 - 2000 was calculated to be about 2.5Q from fossil fuels, 0.5Q from nuclear energy and 0.03Q from hydropower. The total, 3Q, is consistent with published estimates. The fossil fuel reserves alone, including shale oil, are estimated to be in the range of 25 - 30Q while the U_3O_8 reserves at acceptable prices are adequate until the turn of the century when breeders are expected to replenish nuclear fuel supplies. It is concluded that nuclear and fossil fuel reserves in the aggregate are sufficient to supply national energy needs for the foreseeable future. Natural gas alone could not supply these needs until the turn of the century while hydrocarbons, exclusive of shale oil might; shale oil alone, if developed, certainly could do so; the supplies of coal are believed to exceed by a substantial amount all other fossil fuels combined.

National Production of Pollutants By Fossil Fuels 1980 and 2000

If present fuel and pollution control policies are not radically altered, CO and hydrocarbon production, principally from gasoline, will triple by the year 2000; SO_x, which has its principal source in coal, will more than double. Coal would continue to produce, as it did in 1965, four to six times as much SO_x as the next highest producer, fuel oil.

The principal consumers of coal and, therefore, generators of SO_x, are the electrical utility and industrial sectors in that order. However, the major emphasis on abatement of SO_x up to the present has been directed at fuel oil consumers in the utility sector. In view of the rate of increase in energy demand and the urgency of the pollution problem in ever-widening areas of the United States, research and development aimed at containing not only sulfur or SO_x but other pollutants from coal should be aggressively pursued. Consideration should be given to using the

DOD approach of supporting several possibilities simultaneously until one or more optimum methods can be selected.

The production of benzo(a)pyrene, a potent carcinogenic which has its origins in gasoline and coal primarily, is expected to triple by 2000. Hand-fired coal equipment can produce as much as 20,000 times as much of this compound per unit of energy produced as does automatic equipment. Even though the number of hand-fired units is declining rapidly, stringent emission limitations should be imposed. It is highly desirable that epidemiological studies of the incidence of pulmonary neoplasms in coal burning industries and garages be carried out for the purpose of analyzing the correlation, if any, between their occurrence and exposure to benzo(a)pyrene fumes.

The utility of national pollution data, present or projected, is more limited than the corresponding information for regions or large urban areas. The quantity of pollutants generated from fossil fuels, based on 1964 - 65 energy use patterns, projected population increase and projected per capita energy demand, was estimated for the Standard Metropolitan Consolidated Area which includes Chicago. The estimated yield of pollutants was converted to expected atmospheric concentrations in 1980 and 2000. It was concluded that CO will not be an atmospheric pollution problem (California standards) until the year 2000 but that the PHS SO_2 air quality criteria which were exceeded by a factor of four in 1965 will be exceeded by 7-1/2 in 2000.

To achieve these criteria, all users of sulfur containing fuel would have to limit their present (1965) emissions to 0.64 lbs $SO_2/10^6$ BTU. This corresponds to coal containing 0.4% sulfur and residual oil containing 0.6%. This emission maximum will have to be reduced by 0.016 lbs $SO_2/10^6$ BTU/yr between 1965 and 1980 and 0.020 between 1980 and 2000. Application of this standard to Chicago in 1967 would essentially prohibit the use of coal and residual oil in the Chicago, MSCA.

Energy Demand and Production of Pollutants by Sectors 1965 - 2000

Within the industrial sector, the greatest gains will be made by gas and petroleum products in that order, although the use of coal in substantial quantities will continue. Taking into consideration the nature and quantities of pollution products associated with these fuels, priorities for control measures in this sector should be applied in the reverse order i.e. coal, petroleum products, natural gas.

The use of petroleum products in the transport sector will triple while the use of natural gas and coal for this purpose will remain negligible or not significant. As is well known, the internal combustion engine is the primary source of air pollution in this sector.

In the Household and Commercial sector, only the consumption of natural gas is expected to increase substantially - and this will be limited to the 1965 - 1980 period. Electrical heating, in large part nuclear in origin, will undoubtedly make substantial inroads in this sector. Although the use of oil over the next 35 years is projected as remaining essentially static, it is used in sufficient quantity within this sector to warrant application of emission control measures.

The application of emission controls to homes, apartment houses and commercial buildings (as distinguished from factories) has serious political implications with which this report is not prepared to deal. However, political considerations notwithstanding, air pollution control is most effectively obtained by fuel composition standards (e.g. limitations on sulfur content) in combination with emission standards. The combination of composition and emission standards with a system for correlating fuel consumption with meteorological conditions will go far toward alleviating air pollution in the immediate future. It is suggested that the use of air alerts during air pollution crises in large urban areas or regions, implemented via the Civil Defense System, should be evaluated.

Energy Demand and Pollution Production By Electric Utilities 1980 - 2000

Considering the entire nation, the principal air pollution source is coal by 2-4 to 1 over gas and oil combined; this relationship is expected to continue into 1980 and 2000. However, as is discussed at length in the text, regional concentrations come into play so that along the east coast the ratio of SO_x production from coal and oil, in 1965, is 2:1. The implications are clear: the greatest pressure for pollution abatement in the electrical utility sector should be directed against coal. Since no developed methods that are applicable to coal are readily at hand, a large scale research and development program, in which H.E.W. would be an active participant should be initiated. Information at hand suggests that the present government supported program is insufficiently funded to permit an aggressive, diversified attack on the pollution problem from this source.

Nuclear power is expected to make spectacular gains in this sector and to exceed all other sources of electrical power by 2000; by that time, also, electrical power will have increased its share of the total energy market from 20% (1965) to 30%. The AEC projections in the year 2000 for total electrical demand are significantly higher than projections based on current trends. Only a major reduction in costs of delivered power - a development that is not yet visible - make the AEC projections seem reasonable.

Nuclear reactors can be operated in an essentially "clean" fashion with respect to air pollution. The mean life of a fossil-fueled generating station is 35 - 40 years - too long to wait for obsolescence and replacement by reactors to solve the air pollution problem. Consequently, radical new means of fossil fuel modification coupled with selective plant location as well as research on advanced, novel means of electrical power generation (MHD, EGD, fuel cells etc) should proceed simultaneously and be vigorously pressed.

Kr-85 (τ = 10.6 yrs) is the principal long-lived gaseous product that poses a health hazard. Calculation of the world-wide nuclear electrical power generation rates, based on fast and thermal neutron fission, required to approach the maximum permissible atmospheric concentration of this isotope suggests that, at the presently projected rate of reactor proliferation, unacceptable levels will be approached by the end of this century. The technology for (a) containment or (b) conversion via neutron activation of Kr-85 is known and it is concluded that this gas should not pose a health hazard if proper precautions are taken.

The annual dispersion of radium isotopes, which occur naturally in coal, is estimated for the city of Chicago for the years 1965, 1980 and 2000. It was concluded that this source of radioactivity can be readily diluted by added volumes of air and does not pose a health hazard.

Benefits and Costs of SO_2 Air Pollution Control From Coal

The alternatives for SO_2 abatement and/or control from coal were divided into three major groups: (1) continued use of high sulfur coal accompanied by the application of new and advanced technological processes (stack control, solvent refined coal, fuel modification such as gasification, direct energy conversion via the coal-fired fuel cell) (2) substitution by low sulfur coal or (3) substitution by an entirely different energy source. Stack gas treatment is costly (for the limited objective), single-pollutant directed, limited to relatively large fuel consumers and is not yet operationally successful. The same objections apply to solvent refined coal which, in addition, has an inconveniently low melting point and, at present, cannot reduce residual sulfur below 1%. Gasification has the advantage of being multi-pollutant directed, its technology looks promising for the near term and costs, for the results visualized, appear to be reasonable. Direct energy conversion is in an earlier stage of development than either of the above approaches but has the added promise of radically reduced power costs, essentially complete containment of reaction products as well as marked reduction in fuel requirements (extremely high efficiency of energy conversion). The features enumerated as well as the minimal social costs associated with continued use of high sulfur coal make it highly desirable that all facets of modern technology be brought to bear on the development of gasification of coal and direct energy conversion. The USPHS should complement its abatement activities by participating in this process via studies and evaluations of proposed systems and by supporting financially on a large scale those advanced technologies that will make a major contribution toward minimizing atmospheric pollution from fossil fuels.

The use of low sulfur coal in place of high sulfur coal merely reduces the production of one of many pollutants and entails serious, wide-spread social and economic dislocations. While such a step is theoretically possible on a national or regional basis, until a detailed benefit/cost analysis can be carried out and a comparison is made with alternatives, its greatest utility in the immediate future would probably be as a stop-gap measure in the most highly polluted urban areas.

Substitution of high-sulfur coal by natural gas has practical limitations because of limited reserves and distribution systems. Within these limitations, such a course is advantageous for the next 6 - 8 years after which methane from coal and from Latin American natural gas sources would be available. A study of the benefits and costs of such a course, including social and economic costs of (a) substitution in the 1967 - 1975 period and (b) reverse substitution in 1975, i.e., coal-derived methane for natural gas, would be most useful. For comparative purposes, the option involving substitution of naturally low and processed low sulfur residual oil for coal and then the reverse substitution in 1975 should be included.

The possibility of increased substitution of nuclear power for coal was examined. It was clear that additional substitution of nuclear power for coal between 1967 and 1975 - other than what is already committed - is not feasible because of the long lag time for nuclear design, construction, licensing and testing. In the 1975 - 2000 period, commitments for additional nuclear plants are restricted by the limited supplies of attractively priced U_3O_8. By the turn of the century, it is expected that advanced converter and breeder operations will replenish the supply of fissile material. It was concluded that the nuclear power program is and will be making a significant contribution to air pollution abatement but the amount of this contribution up to the year 2000 is circumscribed by time and fuel limitations.

Health Damages

The costs of direct damages such as health impairment, destruction of crops, deterioration of houses etc. caused by air pollution has been the object of much rhetoric and somewhat less serious study. These costs, let alone the indirect costs such as reduced real estate values, extended vacations etc. are known with even less certainty. It is doubtful whether any national cost figures are or will be known with any degree of accuracy. A continuing prime concern is the cost of human illness induced by exposure to air pollution. In view of the complex aetiology and suspected synergistic effects, it is suggested that the paired city technique has the highest probability of yielding meaningful data on this point and on air pollution damages in general. These studies would be illustrative and would permit cost guesstimates, labeled as such, for the nation as a whole. Such data is most useful for estimating changes in national costs.

While several illustrative studies would be helpful in bringing cost estimates up to date and thus in placing them on a firmer base, it is doubtful whether more than a few such studies are required.

A Benefit/Cost Analysis of Solvent Refined Coal (SRC)

A benefit/cost analysis based upon the large scale introduction of the SRC process for reducing the sulfur content of high sulfur coal is treated in some detail. Since the value of direct or indirect benefits, as described above, are not known. The benefit/cost ratio is expressed in terms of tons of SO_2 removed per dollar expended for this purpose. It is concluded that the cost of sulfur removal outweighs the total benefits derived and that the process, therefore, is not an attractive one.

Fuel Policies And Their Relation To Pollution

There is no single national fuel policy other than to assure a continuing supply of energy sources in peace and war. Consequently, fuel policies consist of a conglomeration of laws, regulations, executive orders etc. with roots that are primarily economic. The principal raisons d'etre for some have attenuated with time; the objectives of a number of policies within the Federal Government appear to be in direct conflict with each other.

A complete examination of fuel policies is beyond the scope of this study. However, some aspects, considered to be of major importance, were selected for discussion and comment. These are (a) residual oil (b) regulation of fuel production (c) policies pertaining to fuel utilization (d) the Federal Power Commission and fuel policy (e) coal policies (f) extra-high voltage transmission and interties (g) hydropower (h) the internal combustion engine and (i) natural gas pricing policies and the FPC.

Residual Oil

Since 1960, the national demand for residual oil has remained relatively steady while imports, which average 2.5% sulfur by weight, have increased from 35% to 55% because of reduced domestic supplies. Imports are restricted to the east coast. What was once an economic threat has now become a health threat. It is concluded, therefore, that the rationale for the residual oil import program should be re-examined in the light of changing economic conditions and a greater demand on the part of the public to reduce air pollution. It is suggested that authority should be sought by the Office of Oil Import to make residual oil composition (low sulfur) a criterion for acceptance, that the policy permitting export of large quantities of liquified natural gas (LNG) be reviewed in the light of the present policy of natural gas conservation, and that the possibility of importing LNG from Latin American countries be examined, taking into account such aspects as health implications, economics, domestic politics and international relations.

Regulation of Fuel Production

The regulation of fuel production is almost exclusively a state function. Crude oil and natural gas production is regulated in almost all states by appointive bodies; venting or flaring of gas is generally severely restricted as a conservation and anti-pollution measure. Prices are controlled only indirectly by limiting production.

Policies Pertaining To Fuel Utilization

Pollution considerations are beginning to shape fuel utilization patterns. Stricter enforcement of existing laws, regulations, ordinances etc. at all levels of government as well as the plethora of proposed new laws all indicate that as population density increases, concern for public health and welfare will probably become a primary consideration in fuel selection. Recent legislative proposals that H.E.W. be granted authority to set emission standards for designated industries and that Regional Air Quality Commissions be established, if enacted, would qualify as major air pollution control measures which are indicative of policies which would affect fuel utilization patterns. Such authority could cause H.E.W. to become a major force in shaping national fuels policies.

The Federal Power Commission and Fuel Policy

The role of the FPC, which is an evolving one, in setting natural gas and hydropower policies is traced. The pollution aspects of five land-mark cases are summarized. These are: (1) the X-20 case (2) the Gulf-Pacific, Transwestern, El Paso case (3) the current TRANSCO case (4) the current Con Edison (Cornwall) case and (5) the Florida Gas Transmission case. A review of the briefs and the decisions in these cases - H.E.W. intervened in all but the X-20 case - reveals that federal fuel policy as expressed by the FPC and H.E.W. staffs are in conflict with respect to the expanded use of natural gas by electric utilities. As previously recommended in this report, H.E.W. should (1) sponsor outside sources in making a thorough investigation of the application of advanced technologies to fossil fuels with a view to reducing pollutant production; included would be the coal-fired fuel cell and coal gasification (2) that it undertake to accelerate the research and development processes by large scale financial support and (3) that it investigate the technical and economic feasibility of large scale importation of liquified natural gas. Success in either or both of the gasification options would expand the methane resources of this country to the point where the FPC need no longer make natural gas conservation the pivot in its decisions pertaining to expanded use of this fossil fuel by electric utilities.

Coal Policies

The Interstate Commerce Commission exerts considerable influence on the competitiveness of coal since the bulk of this fuel (70%) is moved by railroad. The remainder is moved by barge and truck over which the ICC also has jurisdiction. In addition, this agency sets rates for oil transported via interstate pipeline and for barges carrying natural gas. The coal-carrying railroads have responded to competition by introducing high-speed, non-stop coal trains and developing "whopper-hoppers." The policy of the ICC has been to foster competition provided rates charged reimburse the carrier for costs and are not destructive of competition.

The FPC has also served the public interest by supporting extra high voltage ($>$ 270 KV) transmission thus permitting mine-mouth coal-fired generating plants to remain competitive and at the same time effecting a reduction in air pollution from electrical utilities in highly urbanized areas.

SO_2 emission standards recently set for federal installations in New York, Chicago and Philadelphia are so stringent as to ban effectively the use of coal and most residual oil. Application of these standards by H.E.W. to industry, which would be permissible under legislation pending in the 90th Congress, could have wide-spread economic and political repercussions. The logical alternative in the near-term is the combustion of natural gas but such a decision would run counter to the present policy of the FPC unless the latter decide that, in those cases where alternate fuels are not available, a formerly "inferior" use is permissible.

Extra-High Voltage (EHV) And Interties

It is the stated policy of the FPC to foster both EHV and interties for purposes of cost reduction and increased reliability. The U.S., Russians and Canadians all have power lines over 700 KV. The U.S. has recently completed major east-west inter-ties which now links the entire U.S. into a single network, should the necessity arise.

The effects on atmospheric pollution of EHV and inter-ties are very complex and it is not possible to sort out the individual factors. Thus reduced rates make for increased power utilization; EHV permits remote siting of power plants and inter-ties result in reduced capital investment but may increase pollution at a given location.

Hydropower

The FPC was originally created in 1920 as a hydropower licensing agency; it still retains this function. Although the number of hydropower facilities - the "cleanest" method of generating electricity - is growing, as suitable sites become progressively more difficult to find, the fraction of the total energy needs of the nation provided by this means will remain stable or will decrease. With a view toward conservation of recreational areas and natural resources, it is now a prerequisite that new hydropower projects make provision for the use of lakes, rivers and the surrounding countryside for recreational purposes and that the power company refrain from despoiling the countryside to the maximum extent possible.

The FPC, by virtue of the 1965 Supreme Court decision in the Taum Sauk case has jurisdiction in those pumped-power projects which result in the interstate transmission of electric power. While such facilities result in capital investment savings by making use of existing generating facilities in off-peak hours, they also result in an increase in the production of fossil fuel pollutants of the order of 50%. Only if the pumping power is nuclear in origin, does this form of hydropower result in no increase in atmospheric contamination.

Internal Combustion Engines

Projections for gasoline consumption, the single greatest source of atmospheric pollutants in the United States in 1965, indicate that if present trends continue, it will increase by factors of 1.8 and 3 in 1980 and 2000 respectively. The principal factors limiting the use of internal combustion engines will be air pollution and road congestion.

One major avenue for the reduction of air pollution being followed by industry and government (in addition to improved combustion and exhaust control of internal combustion engines) is that of battery development. The present limitations associated with the rechargeable type make it doubtful whether they will win wide-spread public acceptance on operational grounds in the immediate future; the best informed opinion is that it will be at least 10 years before these deficiencies are corrected. Further, they can only contribute to pollution reduction if the source of power is nuclear in origin. From an operational and pollution standpoint, some fuel cells look attractive but they still require considerable research and development. Another alternative is improved mass transit systems which in effect reduces the Kw-hr/passenger-mile.

Mass transit systems are being vigorously explored by the Departments of H.U.D., Transportation and Commerce but the extent to which government should support battery and fuel cell development (except for space applications) is a matter of controversy. Consequently, neither of these devices is being developed as rapidly as circumstances require.

It is not clear that the current efforts to both find a substitute for the internal combustion engine and to radically improve mass public transportation are being pursued in a coordinated and systematic fashion. In view of the overlapping interests of H.E.W., H.U.D., the F.P.C., the Departments of Interior, Labor, Transportation and even the State Department, it is recommended that an inter-agency committee be appointed which would serve as a coordinating agency within government and a clearing house for information on government and industry activities.

Funding of Energy R&D

Based on 1963 data and informed opinion of the changes that have occurred since that date, it is pointed that the energy R&D funding to sales ratio is consistent with other technological industries. However, within this sector, the distribution of funding favors gas and oil on the one hand and newly developing energy conversion techniques on the other. It is recommended that R&D funds FOR COAL be increased by at least a factor of two, preferably more.

CONCLUSIONS

1. The alterations in the selection of energy sources 1947 - 65 can be ascribed to inter-fossil fuel competition, consumer preference and regulatory policies; during the above time span anti-pollution measures have played only a minor role. In view of the numerous recent anti-pollution regulations promulgated and the number of laws proposed at federal, state and local levels, there is little doubt that public health considerations will play a progressively larger role in the future in determining energy sources and policies.

2. Energy consumption per capita in the 1947 - 65 period increased faster than the population, but improved efficiency in energy conversion and utilization have held back the rate of appreciation.

3. In comparison with 1965, the 1980 and 2000 annual energy demand will expand by 60% and 170% respectively while the population will have increased only 29% and 72%.

4. Fossil fuels will lose a substantial fraction of the energy market to nuclear fuel (fission) by 2000, although the absolute quantity of each fossil fuel burned is expected to increase from 60% (natural gas) to 150% (petroleum products).

5. About 3Q total energy will be consumed between 1965 and 2000. This demand could be satisfied by coal or shale oil reserves alone (~ 18 and 5Q respectively) but by neither non-shale oil petroleum products nor natural gas.

6. Since World War II the annual coal requirements (BTU) have been decreasing. This trend in the total use of coal has ceased, and will probably be reversed in the near future, primarily as a result of the greatly augmented demand by the electric utilities.

7. In the aggregate, natural gas produced significantly less pollutants in 1965 than did coal, the low-boiling petroleum fractions or fuel oil, in spite of the fact that it supplied about 25% more energy than any of the other fossil fuels. Only its production of aldehydes and organic acids are believed to have exceeded those from other fossil fuels.

8. If present national fuel trends are not radically altered: by 2000, the production of CO and hydrocarbons will triple, that of SO_x will more than double; better than 90% of the CO and hydrocarbons will continue to be produced by the low-boiling petroleum fractions, mainly gasoline; more than 90% of the SO_x will continue to originate in fuel oil and coal with the latter producing 5 - 6 times as much as the former. Even in the east coast megalopolis stretching from Washington

to Boston, coal produces almost twice as much SO_x as does oil; whether this ratio continues will depend on future air pollution policies.

The chief target for CO and hydrocarbon emission control must continue to be gasoline and the internal combustion engine. It is conceivable that CO, which is not now an atmospheric pollution problem, could attain unacceptable concentrations in some sections of the nation by 2000.

The use of new energy sources, anti-emission devices, more economical use of fuel etc. will only delay, not eliminate, the need for controlling the emissions from internal combustion engines.

The production of benzo(a)pyrene, a known potent carcinogenic, will more than triple by 2000. The principal sources are and will probably continue to be gasoline and coal.

9. On a national basis, coal contributes over 80% of the atmospheric sulfur dioxide. Even on the east coast where the consumption of residual oil per unit area is greater than anywhere else in the nation, coal produces about twice as much sulfur compounds as do the petroleum products.

These disparate ratios are expected to continue to 1980 and beyond unless countermeasures, in the form of emission control, fuel modification and fuel substitution, are initiated.

10. About one-third of the national consumption of residual oil was confined (1964) to the east coast between Washington, D.C. and Boston. About 30% of the approximately 100 million barrels of residual oil burned by electric utilities (1964) took place in New York and New Jersey. Therefore, when considering pollution abatement from residual oil, the east coast must be the principal target.

11. In Chicago, which is typical of a highly industrialized urban area, CO atmospheric concentrations are not expected to exceed California standards, the only ones extant, until about the year 2000. NO_x levels will not be of concern even after 2000 (West German standard). The PHS air quality maximum for SO_2 (hourly sampling) which was exceeded by the annual maximum average by a factor of four in 1965 could be exceeded by a factor of 7-1/2 by the year 2000.

The present maximum ratio of 0.65 lbs $SO_2/10^6$ BTU required in emissions from Federal installations will have to be applied to all Chicago emitters in order to meet PHS air quality criteria. In order to maintain these levels, permissible SO_2 emission will have to be reduced by 0.016 lbs/10^6 BTU/yr 1965 - 80 and 0.020 lbs/10^6 BTU/yr 1980 - 2000.

(a) Application of the above rule limiting the ratio of SO_2 per million BTU from Federal installations in New York, Chicago and Philadelphia to electrical utilities and industry, could effectively prevent the use of coal in those cities.

(b) Calculations based on the use of coal in the Chicago area suggest that naturally occurring radium found in fly-ash can be readily diluted below MPC levels.

12. Substitution of high sulfur coal by low sulfur coal, natural gas and low sulfur residual oils can be accomplished in the immediate future but these substitutions will probably have to compete with gasified coal starting in 1975. Each substitution would have serious social and economic repercussions. Benefit/cost analyses of these alternatives would be helpful in reaching policy decisions.

Substitution of high sulfur coal by nuclear power, which is limited to the electrical utility industry, is already taking place at the maximum rate permitted by acceptably priced U_3O_8 reserves.

(a) At least 50% of the coal applications are not substitutable by electrical energy and, therefore, will not be affected by the new technologies such as fission, fusion, MHD, EGD, fuel cells, direct solar energy conversion thermionics etc.

13. A benefit/cost analysis of the solvent refined coal process leads to the conclusion that this method of dealing with sulfur from coal is not an attractive one at present.

14. Atmospheric pollution form Electrical Utilities will become increasingly self-limiting as nuclear energy becomes more competitive and replaces fossil fuel.

(a) Although the fraction of energy supplied to this sector by coal will drop from about ½ to 1/3, the tonnage burned in both 1980 and 2000 will be about double the quantity consumed in 1965.

(b) Among the fossil fuels in this sector, the principal source of energy was coal by 2:1 (1965); this ratio is not expected to change radically in 1980 or 2000. Therefore, coal is and will continue to be the primary source of atmsopheric pollutants.

(c) Within this sector, data on present and projected oil demand indicate that tis consumption will at no time between the present and 2000 exceed 8% and 10% of the total fossil fuel and coal combustion respectively.

15. Although hydropower is the "cleanest" of the electrical power generators, its contribution, percentage-wise, to pollution abatement in the near future will be a progressively decreasing one because the number of economically competitive sites is limited.

16. In the Industrial sector, all three fossil fuels are used in quantity and, therefore, contribute substantially to air pollution. Up to the year 2000, petroleum and natural gas are expected to show the greatest advance in consumption.

The production of pollutants by the Transport sector, originating almost exclusively from the combustion of petroleum products, could increase by a factor of three between 1965 and 2000.

Substantial quantities of oil and natural gas are used in the Household and Commercial sector but only the latter fuel is expected to show an appreciable escalation in consumption up to 1980. Between 1980 and 2000, projections do not indicate much change in the utilization of either fuel. The quantity of coal used by this sector is trivial.

17. Present trends suggest that the United States is moving in the direction of an electrical economy, as is indicated by the fact that the electrical power industry will expand its share of the energy market from 20% in 1965 to 30% in 2000. By the latter date, it is anticipated that nuclear fission

will be the source of more than 50% of the thermal energy required for electrical generation.

(a) The AEC projection for total electrical demand in 2000 is extraordinarily high and is inconsistent with other projections based on present trends; the former would be more acceptable if there are major reductions in power costs stemming from technological innovations such as breeder and advanced converter reactors, MHD, fusion, and fuel cells.

(b) By 2000, Kr-85, produced as a result of the fission process, could become a health hazard if permitted to escape to the atmosphere. The technology for conversion to a stable isotope via neutron activation or containment is known and can be applied routinely.

18. The coal-fired fuel cell might, if fully developed, accelerate the trend toward an electrical economy because of its high conversion efficiency and, therefore, low production costs. The wide-spread employment of this device could have broad social implications including those stemming from essentially complete containment of combustion products.

19. By the year 2000 the population will have increased by no more than 75% while gasoline consumption (barring major changes in methods of propulsion) will triple.

(a) The use of electrically propelled cars in the near future would require that projections of electric generating capacities and pollution from fossil-fueled generators be revised drastically upward.

(b) By the year 2000, if one assumes that about half of all automotive travel is by means of electrically propelled cars and that gasoline requirements increase in accordance with present trends, gasoline consumption would only be curtailed to the 1980 level while the production of combustion products in fossil-fueled generating stations (assuming 50% of the total are nuclear) would be substantially increased as a result of the escalated power demand.

(c) Internal combustion engine emission standards are a moving target requiring frequent revision, possibly as often as every 2 - 3 years.

20. Accurate data on total damage and health costs caused by atmospheric pollution is fragmentary; its lack is indicative of the difficulty associated with acquiring such data. Relative values using indices of pollution damage will probably suffice for most purposes. However, a few "paired-city"

studies of disease costs associated with a marked difference in atmospheric concentration of a single or a small number of pollutants would be useful as a base for projecting national costs.

21. There is no coordinated federal and/or state fuels policy; current practices consist of improvisations. When one considers the national interest in a broad sense, some of these policies are in conflict with each other while the basis for the existence of others has altered radically with the passage of time.

(a) On the record, the FPC and HEW staffs appear to have strongly divergent views with regard to the use of additional quantities of natural gas by electric utilities in those urban areas demonstrating high atmospheric concentrations of SO_x and other pollutants.

(b) A joint evaluation by HEW and the FPC of the implications for domestic natural gas reserves of (1) potential or incipient technological innovations associated with new or modified energy sources such as coal gasification and the coal fired fuel cell and (2) the availability for importation of large volumes of LNG from friendly Latin American and African countries, might resolve the current divergence in posture between the two agencies.

NOTE

22. A high-level Science Adviser to the Federal Power Commission, one who has broad interdisciplinary competence, could serve a most useful function within the FPC and in its relations with other government agencies, especially with H.E.W.

23. Current negotiations among gas producers, pipeline operators and the FPC to reach an agreement on an acceptable formula for pricing natural gas could have far-reaching implications for the competitiveness and, therefore, demand for this fuel.

24. The total funds allocated by both industry and government for R&D on coal is minimal and inconsistent with similar allocations for natural gas and petroleum products whether one considers current sales, magnitude of resource, or pollution potential. If the escalating pollution threat from this source is to be aborted, then R&D funds should be materially increased.

RECOMMENDATIONS

IT IS RECOMMENDED THAT:

1. A continuing body, a National Committee For Pollution Criteria, consisting of experts from both within and outside government, be appointed; its responsibilities should include all aspects of the human environment in addition to air pollution.

    (a) Air Pollutants be ranked, for control and abatement purposes, in a priority system which not only takes into account production, emission or atmospheric concentration, but also relative toxicity and the recovery factor, if any.

    (b) A high priority be accorded the setting of air quality criteria and emission standards for benzo(a) pyrene.

    (c) A survey of the incidence of pulmonary neoplasms in individuals chronically exposed to combustion fumes from coal be carried out to determine whether there is a correlation with benzo(a)pyrene concentration.

2. The Department of H.E.W. seek the creation of an interagency fuel policy council which would coordinate the fuel policies of the Federal Government and that the Department

of H.E.W. participate in its operation in order to give due weight to its views with regard to pollution.

3. The USPHS undertake a comprehensive evaluation of all those advanced technological processes under development which could significantly affect air pollution and that it publicize its interest in being informed about and in supporting new ideas. Notable among processes already under development are (a) coal gasification and (b) direct energy conversion in the coal-fired fuel cell.

   a. It is recommended that the USPHS participate in the support of those projects in other agencies it deems most worthy from an anti-pollution point of view.
   b. It is recommended that the USPHS carry out its evaluation of those processes that relate to areas of responsibility of the FPC, especially those pertaining to coal gasification and direct energy conversion, in cooperation with the FPC. Such a cooperative effort might reduce substantially or eliminate the current differences between the two agencies with regard to fossil fuel utilization policy.
   c. It is recommended that, as a part of the evaluation process, trade-off comparisons that take into account not only economic but social consequences be made.

4. The Bureau of Disease Prevention and Environmental Control "build bridges" to other government agencies, universities and industrial laboratories that have overlapping interests via individuals especially detailed for this purpose. Examples are mass urban transit in H.U.D.; urban renewal schemes in universities; and megalopolis high speed ground transport programs in the new Department of Transportation.

It is further recommended that the Bureau participate in the support of those programs it feels will contribute most substantially to its missions.

5. The rationale for our oil import policy be re-examined in the light of evolving economic and health considerations and that the apparent inconsistency between limiting the use of natural gas by electric utilities on the grounds of "inferior" use on the one hand, and exporting substantial quantities on the other, be reviewed.

6. The Public Health Service follow the lead of Los Angeles and evaluate, in cooperation with the appropriate states, the impact of limiting or banning the construction of new fossil fueled electrical utility plants in selected areas which demonstrate undesirably high concentrations of atmospheric pollutants. Such a study should analyze not only health but economic consequences.

7. The social and economic implications of substituting low sulfur coal, natural gas and low residual oils for high sulfur coal be evaluated by means of benefit/cost analyses and that policy recommendations be made to appropriate government agencies on the basis of these analyses.

8. A benefit/cost analysis of the impact of nuclear energy on fossil fuels and their associated production of pollutants, especially coal, should be carried out in two phases (1) 1975 - 2000 to cover the non-breeding phase of reactor development as well as technological developments affecting fossil fuels and (2) post-2000 when breeders are expected to be operational. In making such a comparison, reactors should be credited with a pollution abatement "benefit"; such a credit is not now the practice.

9. A comprehensive study of the resource adequacy, economics, technology and social and political implications of importing LNG from Latin American countries, notably Venezuela, be initiated.

10. A study be made of medical and related costs associated with atmospheric pollution using the "paired-city" approach.

11. Coal should be the chief target for SO_x reduction when one is considering the nation as a whole, or even when one is considering the megalopolis stretching from Washington, D.C. to Boston where more than one third of the national consumption of high sulfur residual oil is consumed.

12. The R&D budget for coal be at least doubled and emphasis be placed on those processes that have pollution abatement potential. The 50-50 funding split between industry and labor, which now obtains, appears to be reasonable.

R&D on coal with emphasis on de-pollution be prosecuted aggressively using the D.O.D. approach of supporting several promising systems simultaneously.

13. All aspects of our national natural gas policies, taking into account such aspects as economics, foreign policy, potential technological developments, resource adequacy, pollution, etc. be examined with a view to developing a coherent, consistent, and coordinated program.

14. Air pollution abatement measures in the Industrial sector be directed at all three fossil fuels; control efforts intended to meet increases in this sector should concentrate on petroleum products and natural gas.

15. Control and abatement efforts for the Transport sector be a continuing and major one with particular emphasis on developing acceptable alternative energy sources. Government should assume the leadership both in funding and coordination since it is doubtful whether industry has sufficient incentive to do the job.

16. In the Household and Commercial sector, control and abatement measures should be directed primarily against petroleum products (distilled and residual oils).

17. In view of the lack of any promising prospects in the near term (0 - 10 years) for replacing the internal combustion engine with less objectionable (from a pollution stand-point) propulsion units and the projected tremendous increase in the combustion of petroleum products to the year 2000, all facets of the programs directed at control and abatement of these products be continuously and vigorously pursued in depth.

18. All nuclear generating stations be built with provisions for containing Kr-85 and that all nuclear fuel processing plants contain this gas or, preferably, convert it to stable Kr-86.

19. The use of Civil Defense systems in implementing alerts during periods when atmospheric pollutants reach unacceptable or dangerous levels be explored.

I. Introduction

This study is primarily concerned with atmospheric pollution from energy sources, fossil, nuclear and hydro. In order to gain a better understanding of the forces at work which will shape the pollution problem that must be faced in ensuing years, it is necessary to evaluate recent historical patterns, see where we stand today and, most important, insofar as possible, to look ahead at least a quarter of a century. In the following discussions, the years 1980 and 2000 have been selected as convenient reference points. In reviewing the past and present, and attempting to adumbrate the future, some of those policies, explicit, implicit, and governmental, that have influenced energy source patterns and, therefore, atmospheric pollution are identified. As an adjunct, the methodology of dealing with the economics of selected technological developments is summarized and a benefit/cost analysis for one is carried out in some detail.

II. Historical: 1947 - 1965

In 1950, the total U.S. resident population was 152 million; in 1965 it reached 195 million, an increase of 28%. In the same period, the gross national product and personal incomes, both expressed in 1958 dollars, rose 72% and 82% respectively[1]. Thus the production of goods and services per capita, i.e., productivity, increased by a factor of 2-1/2 in 15 years.

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[1] Statistical Abstracts of the U.S., 1966, p.321.

The increase in total population, the higher GNP and the augmented individual incomes all combined to increase the energy demand from 34.2×10^{15} BTU in 1950 to 54.5×10^{15} BTU in 1965[1], an increase of 56% while the population increased by only half this amount. This level was achieved in annual increments varying from -3.4% to 9.9% and averaging 3.3%/yr. (Table 1). Comparison of this growth rate with indices of the economy such as per capita income, new construction, number of households, GNP, etc. indicates that energy use grew somewhat more slowly than these indices. Such a relationship suggests an improvement in the efficiency with which energy sources were utilized. This is certainly true with respect to coal which today requires only 0.86 lb. to produce 1 Kw-h as compared with 1.33 lb. in the immediate post-World War II period (see Table 8).

II.A. Breakdown by Fuel Source and Sector

A breakdown of total energy utilization by fuel source (Table 2) permits one at once to gain some insight into the changing consumption patterns and consequently of qualitative and quantitative trends in the atmospheric pollution burden. Thus in 1947, coal comprised about half of the total energy source while in 1965 it was down to about a quarter. In terms of tonnage, however, coal has probably "bottomed out" since coal

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[1] Statistical Abstracts of the U.S., 1966, p.528; preliminary estimate.

Table 1

U. S. Annual Consumption of Energy[1] and Annual Increments: 1950 - 1965

Energy Sources: Fossil Fuels, Hydro and Nuclear

Year	Energy Consumed BTUx10^{15}	Annual Increment Per Cent
1950	34.2	-
1951	36.9	7.9
1952	36.6	-0.81
1953	37.7	3.0
1954	36.4	-3.4
1955	40.0	9.9
1956	42.0	5.0
1957	41.9	-0.23
1958	41.5	-0.96
1959	43.5	4.8
1960	44.8	3.0
1961	45.6	1.8
1962	47.6	4.3
1963	49.6	4.2
1964	51.7	4.2
1965	54.5	5.4
	Mean	3.3

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[1] "Gas Facts, A Statistical Record of the Gas Utility Industry in 1965," Table 13, p.20.

demand, barring drastic curtailment by anti-pollution laws, can be expected to increase with a rising population. Thus the Department of Interior has reported that coal usage reached 465 million tons in 1965 (Table 2) in comparison with 442 million in 1955. Coal is not the only energy source that has had "rough going" with respect to the total energy market during the past 10 years. By 1955, petroleum had captured 42% of the total energy market but in the following 10 years, it was barely able to hold its own - 40% in 1965. Again, however, in those 10 years, the population increase of 17.5% and greater individual affluence combined to raise the use of liquid hydrocarbons by 29%. Most of this increase in the combustion of petroleum products took place in the internal combustion engine for, in the 1955-65 time span, car, truck and bus registrations rose from 62 million to 90 million, an increase of 31%.

The star performer between 1947 and 1965 has been natural gas. In this period, its use has increased by over a factor of four while its slice of the energy market increased from 12% to about one-third. However, due to competition and dwindling reserves, the projection is that its use in the next 15 years will increase by only 50%, while its share of the market will remain essentially static (see Tables 12 and 13).

Since 1947, hydropower, the "cleanest" of the major energy sources, has been losing ground to other segments of the U.S.

Table 2

U. S. Gross Consumption of Energy Resources[1]

1947, 1955, 1965

	1947			1955			1965		
	%	therms x 10^9	* x 10^9	%	therms x 10^9	* x 10^9	%	therms x 10^9	* x 10^9
Coal	50.2	158.3	0.601	30.9	116.4	0.442	24.4	122.6	0.465
Nat. Gas, dry	12.4	39.1	3753	23.0	86.8	8318	31.5	158.4	15,194
Petroleum[2]	32.7	103.2	1.807	42.1	158.6	2.822	40.3	202.4	3.641
Hydropower[3]	4.7	14.7	1.459	4.0	15.1	1.497	3.8	19.2	1.90
Nuclear[3]	-	-	-	-	-	-	0.07	0.36	0.037
Totals	100.	315.3		100.	376.9		100.	503.0	

* Coal: short tons; natural gas: ft^3; petroleum: bbl (42 gals); hydro- and nuclear power: equivalent short tons of coal based on historical average rate of kg. of coal/kw-h at central electric stations.

[1] Adapted from "Pattern of Energy Consumption in the U.S.," W. A. Vogely and W. E. Morrison (U. S. Bureau of Mines, Washington, D.C.) World Power Conf. Oct. 16-20, 1966, Tokyo.

[2] Includes natural gas liquids.

[3] Therms based on historical and projected national average rate of kgs. of coal/kw-h at central electric stations.

energy market. Thus according to Table 2, it contributed 4.7% in 1947 and 3.8 in 1965. By January 1, 1965, about 25% of the hydroelectric resources of the U.S. were already in use (42 million KW out of 159.8 million KW)[1] and there do not appear to be any technological or economic factors that suggest this fraction will increase. On the contrary, as the fraction of the total hydro-resources utilized increases, availability of only the less economic sites will cause a slowing down of hydroelectric construction. In ensuing years, this source of power is expected to contribute less than the 4.2% of 1965[2].

Considerable additional information is gained by discerning trends pertaining to the use of individual fossil fuels within economic sectors. Table 3 presents such sector data for the years 1947, 1955 and 1965.

It is immediately apparent that while the use of coal in households and commercial enterprises has suffered drastic reductions percentage-wise, that coal has lost half of its segment in industry and has virtually disappeared from transportation, its use in electrical utilities represents an expanding market. Therefore, the "bottoming out" of coal referred to previously indicates that the utility market gains are catching up with the losses in the other sectors.

[1] Federal Power Commission Annual Report for 1965, p.75.

[2] National Power Survey, Part 1, 1964.

Table 3

Per Cent Distribution of Energy Sources*

By Consuming Sectors: 1947, 1955, 1965**

	Coal	Gas	Petroleum	Hydro	Nuclear	Sector Total
Household and Commercial						
1947	10.2	3.4	6.8	-	-	20.4
1955	4.4	7.1	10.1	-	-	21.6
1965	1.0	10.5	9.6	-	-	21.1
Industrial						
1947	21.9	8.7	7.5	-	-	38.1
1955	14.6	11.7	8.3	-	-	34.7
1965	10.2	13.7	8.0	-	-	31.9
Transport						
1947	9.1	neglig.	17.4	-	-	26.5
1955	1.2	0.64	22.8	-	-	24.7
1965	0.04	0.93	22.7	-	-	23.6
Electric Utilities						
1947	6.3	1.2	1.4	4.4	-	13.3
1955	8.7	2.9	1.3	3.8	-	16.7
1965	11.2	4.4	1.2	3.5	0.07	20.4
Miscellaneous						
1947	0.04	0.4	1.2	-	-	1.7
1955	0.30	0.6	1.4	-	-	2.3
1965	0.30	1.1	1.6	-	-	3.0

* For total energy consumed by source, see Table 2.

** Adapted from Vogely and Morrison, "Pattern of Energy Consumption in the U.S.," World Power Conf. Oct. 1966.

Examination of data on gas sales discloses that transportation vehicles burn a very small fraction of the total natural gas used, that industry has consistently been the largest user but that the rate of increase has been greatest in households and commerce, as well as in electric utilities. Thus all gas sectors, including transportation, have demonstrated significant expansion.

In the period 1947 - 1955, petroleum and its products made the most significant gains percentage-wise in the transportation, and household and commercial sectors; industrial and electric utility gains were slight or non-existent. Since 1955, the fraction of the energy market that this fossil fuel supplies has remained essentially static or has declined slightly.

Hydro and nuclear energy is used, of course, only in the production of electricity. But here we see two opposite trends. Hydropower, in spite of the addition of numerous generating plants, as stated above, has not been keeping up with the expanding market. Consequently, its share of the total energy demand shows a decreasing trend. On the other hand, nuclear power was generating 360 million therms by 1965 (Table 2), and had captured slightly less than 0.1% of the market. Thus, although there is general agreement that nuclear power in 1965 is competitive with power from other sources and that its future is bright indeed, the alterations in the utilization of the various fossil fuels in the 1947 - 1965 period must be ascribed to inter-fossil fuel competition, the preferences indicated by consumers (such as the substitution of gas for oil in the household and commercial sector) and the imposition of governmental regulatory policies. The initiation of the Oil Import Administration in 1959 on national defense grounds and the ban on the burning of residual oil in the Los Angeles area for anti-pollution reasons, would qualify under governmental policies.

The trends suggested by the data are expected to be further modified in the future by the factors mentioned above, by resource depletion, by an increasing awareness of the need to control atmospheric pollution and, equally important, by the coming-of-age of nuclear reactors.

II.B. Pollutants and 1965 Pollutant Levels

The identity of the atmospheric pollutants from energy sources has been established although their physiological effects following chronic or intermittent pulmonary exposure at very low concentrations is less well known. Thus it is not yet possible to assign "figures of demerit" to specific compounds with any degree of certitude. The Spilhaus Report[1] has estimated that the total emission, presumably for the year 1965, including the contribution from refuse combustion, as indicated in Table 4.

[1] Publication 1400, NAS-NRC, Waste Management and Control 1966, p.11.

It is apparent that transportation, which depends upon the internal combustion engine, by contributing pollutants that are in the aggregate three times the weight of those contributed by industry, is the major offender. Gasoline and kerosene contain relatively little sulfur, but do produce substantial amounts of CO, hydrocarbons including unburned gasoline vapor and oxides of nitrogen. Data are available which would permit breaking these numbers down further. For example, by combining emission factors (Mayer, 1965) for each type of energy source with average daily demand figures (Vogely, 1966) one can estimate the contributions to atmospheric pollution made by each energy sector (Table 5). It is immediately apparent that the total daily weight is between 1 and 2 billion pounds and that the low-boiling petroleum products contribute by far the greatest proportion - more than twice the total of the other fuels combined. The data also make quite clear that the daily contribution of CO exceeds any other individual contaminant with fuel oil, gas and coal contributing relatively little ($< 8\%$) in comparison with the lighter petroleum fractions (major sources of contaminants are underscored). Similarly the lighter fractions of petroleum contribute almost all of the atmospheric hydrocarbons whereas coal is the source for over 80% of the sulfur compounds.

There is no outstanding source of NO_x since these compounds are a by-product of all combustion. On the other hand, aldehydes appear to emanate primarily from fuel oil.

Table 4

Estimated Annual Production of Atmospheric Pollutants in the U. S.*

Pollutant		(tons/yr) x 10^6	Per Cent of Total
Carbon monoxide		65	52
SO_2 and SO_3		23	18
Hydrocarbons		15	12
Particulate matter		12	10
NO_x		8	6
Other gases and vapors		2	2
	Total	125	100

Source			
Transportation		74.8	59.9
Industry		23.4	18.7
Utilities		15.7	12.5
Space heating		7.8	6.3
Refuse		3.3	2.6
	Total	125.0	100.

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* NAS-SRC Publication 1400, 1966, p.11. These data presumably refer to 1965.

Benzo(a)pyrene is extremely sensitive to the kind of combustion equipment employed; Mayer (1965) has reported variations in emission ratios of over 20,000. Hence, coal could be a major or minor source of this particular carcinogen. Particulate production[1] from coal is also sensitive to the equipment in use - resulting in the range indicated in Table 5. However, even with minimal production from coal, the latter is still, by far, the principal source of particulate matter.

In summary, gasoline is the principal producer of four of the pollutants listed while coal qualifies for three. NO_x and organic acid production cannot be correlated with any one fuel. Note should be taken of the fact that natural gas produced, in the aggregate, less pollutants than either coal, low boiling petroleum products or fuel oil in spite of the fact that the energy it supplied substantially exceeded that of the other three categories[2]. Further, only its aldehyde production exceeded that of coal, only its organic acids exceeded that of gasoline and only its benzo(a)pyrene production may have but most probably did not exceed that of coal.

[1] A distinction is made in this study between "emission" and "production." The latter refers to products of combustion. However, the fraction of each product emitted to the atmosphere can vary between 0 and 1.

[2]

	10^{12}BTU - 1965
Natural gas:	15,800
Coal:	12,300
Gasoline:	12,400
Fuel Oil:	7,800

Table 5

Estimated Daily Emissions From Fossil Fuels - 1965

National Production

	lbs/day - 1965(1)				
	Petroleum Products				
	Gasoline (2)	Fuel Oil (3)	Nat. Gas	Coal (4)	Total
CO x 10^6	790*	0.147	.0117	0.65 to 64.1	791 to 854
Hydrocarbons x 10^6	142	0.246	neglig.	0.26 to 12.8	142 to 155
SO_x x 10^6	2.44	21.2	.0173	97.6	121
NO_x x 10^6	30.6	12.7	11.1	20.6	75.0
Organic acids x 10^6	1.09	n.a.**	2.69	n.a.	3.78
Aldehydes x 10^4	109	18.8	0.348	0.052	128
NH_3 x 10^4	54.4	n.a.	1.31	n.a.	55.7
Benzo(a)pyrene	180	7.2	5.4	1.7 to 33,800	194 to 34,000
Particulates x 10^6	2.99	1.44	0.736	24.4 to 244	29.6 to 249
Total x 10^6	968	35.9	14.6	143 to 439	1164 to 1459

* Underscored - principal producers of effluent substance.

** n.a. - not available.

(1) The population and energy demands were assumed to be those in Tables 4, 6 and 7.

(2) Emissions from gasoline, jet fuel, kerosene and liquified gas assumed to be the same. Gasoline/fuel oil ratio from "Petroleum Facts and Figures, 1965" American Petroleum Institute.

(3) Emissions from distilled and residual fuel oil assumed to be the same except for sulfur which was assumed to be 1.6% and 0.43% for residual and distilled oil respectively.

(4) Particulate emissions from coal vary with the ash and equipment used; a mean residue of 9.5% was assumed (W. S. Smith, 1966), 2% sulfur in coal (Rohrman and Ludwig, 1965); other emission ratios according to Mayer (1965).

For purposes of pollution control or abatement, one is always concerned with fuel source; it is sometimes helpful also to be able to tie it to an economic sector. Major fuel sources have been identified above from the data in Table 5. Referring to Table 3, one can then correlate this information with economic sectors. Gasoline and other low-boiling fractions are the principal sources of CO. Referring to Table 3, transport use in 1965 accounted for more than twice the amount of petroleum products than was consumed by the next highest user, the Household and Commercial sector. A similar statement applies to hydrocarbons, aldehydes and ammonia. In 1965, SO_x, benzo(a)pyrene and particulates emanated chiefly from coal and, referring to Table 3, the principal sources were the electrical utilities and industrial sectors.

III. Future Energy Requirements

Table 2 illustrates the increase in total energy requirements resulting from both increased population and per capita utilization[1] as well as the change in the national "mix" of fuels. These figures are matters of historical fact. Over the years, there have been numerous attempts to forecast energy sources and requirements in order that the nation may be better prepared to allocate its resources wisely. Of secondary importance in these studies have been considerations pertaining to atmospheric pollution and its consequences, both economic and socio-medical. The most recent study was initiated in 1963 by the Office of Science and Technology and was issued in December, 1966. It is a compendium of separate papers prepared by approximately 125 authors and special contributors, an equal number of reviewers and double that number of industry advisory committee members.

Generally, the various energy projection studies have selected target dates of either 1980, 2000, or both. These projections have been based upon one or more indices of energy demand such as population projections; extrapolations of per capita electrical energy demand; GNP estimates based on working hours, productivity, labor force, etc.; or combinations of these and other parameters. The projections represent, with various degrees of confidence, expectations based upon trends provided costs, research developments, consumer preference and government policy follow anticipated broad, general lines. On the other hand, it is not difficult to visualize, for example, the impact on energy demands of the "quiet revolution" in attitudes toward birth control that has been gaining rapid momentum in the last three years. Such unpredictable factors could require substantial revision of future energy demands and pollution loads.

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[1] In 1945 the per capita/yr utilization factor was 238 x 10^6 BTU; in 1965 it had risen to 281 x 10^6 BTU/yr (estimated). Source: Gas Facts, Table 16, p.22.

A number of energy projection studies, most of which take into account population projections, have been published since 1958. (For a list of references, identified in Table 6, 9, 10 and 11, see bibliography.) Those that specified 1980 and/or 2000 are listed in Table 6 along with the mean deviations. For comparative purposes the 1965 energy data from Table 2 are included. It will be observed that (1) the energy/capita is expected to increase by > 75% by 2000, and (2) the per cent deviation of total energy demand for 1980 is only 2.3% but, as one would expect, because of the larger uncertainties associated with longer range estimates, the deviation for the year 2000 is much larger (12%).

In Figure I, the historical and projected population, total energy, energy per capita as well as the GNP and GNP/unit energy are plotted. The GNP data reflects the average annual increase 1945 - 65 of 5.28%/yr, although it should be pointed out that 4 - 4.25% is more representative of the 1955 - 65 period.

Table 6

Summary of Energy Consumption and Population Projections

1965 - 2000*

	10^{15}BTU		
	1965	1980	2000
Clark, SRI, 1967		87.1	
Vogely and Morrison, Dept. of Interior (1966)	50.6	83.8	
Texas Eastern Trans. Corp. (1961)		82.6	
Lasky Group (1962)		82.0	
Teitelbaum (1958)		80.9	
Lamb (1959)		78.0	
Searl (1960)		86.2	170
AEC (1962)		82.0	135
Landsberg, RFF (1963) median		79.2	135
Sporn (1959)			105
AEC (1967) median **		80.0	130
Mean	50.6	82.4	136
% Mean Dev.	-	2.3	12

		x 10^6		
		1965	1980	2000
Population	Mean	194.6	251	335
	% Mean Dev.		2.6	8.1

	1965	1980	2000
Per capita energy consumption, BTU x 10^6	260	328	406

---

* Compiled from Table 1-11, Energy R and D and National Progress, 1966; U. S. Statistical Abstracts, 1966; and Vogely and Morrison, "Pattern of Energy Consumption in the U.S.," World Power Conf., 1966; 1967 Supplement to the 1962 AEC Report titled "Civilian Nuclear Power - Report To The President."

** Omitted in calculating mean; this data was received too late to permit its integration and use in other calculations.

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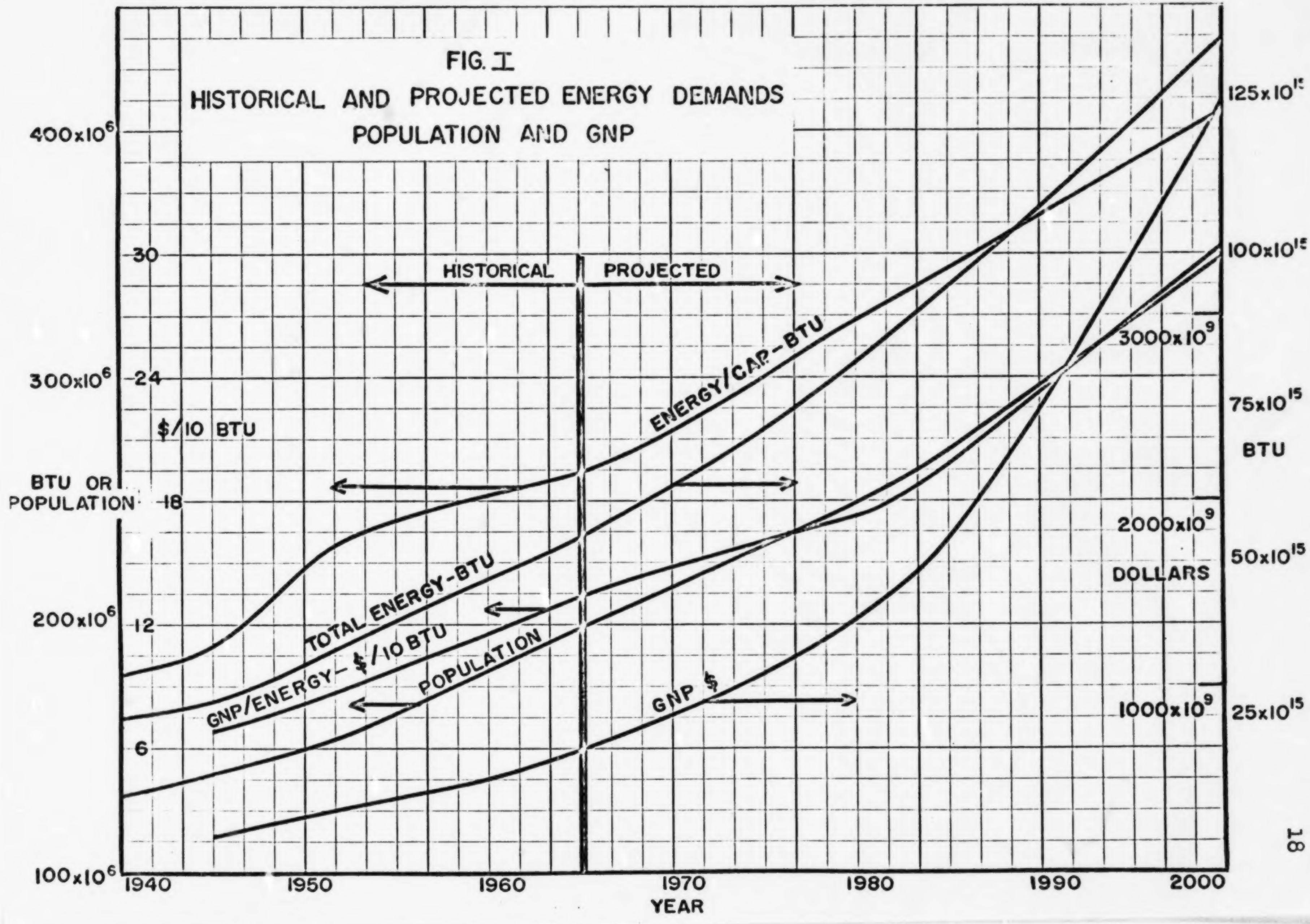

FIG. I

HISTORICAL AND PROJECTED ENERGY DEMANDS POPULATION AND GNP

The estimated increases in energy requirements for the years 1980 and 2000 do not parallel the increase in population. This is to be expected for historically the trend is toward an increase in per capita energy utilization (Table 7) because of higher productivity and an increasingly higher standard of living. These factors are partially compensated by the increased efficiency with which energy is utilized as exemplified by the electrical utility industry (Table 8) and GNP/unit energy (Fig. I). Thus the annual total energy requirements are expected to increase by 60% and 170% from 1965 to 1980 and 1965 to 2000 respectively, while the population will be increasing by only 29% and 72%.

III.A. Projected Cumulative Energy Demand: 1965 - 2000

Using the mean total energy projection of 136×10^{15} BTU for the year 2000 appearing in Table 6, and the relatively accurately known figure of 50.6×10^{15} BTU for 1965, a mean annual increment of 2.85% was calculated. The cumulative total energy requirements from 1965 to 2000 are then given by:

$$\Sigma E = E_o \left[(1 + r)^n - 1\right]/r \qquad (1)$$

Where: r is the annual increment expressed as a fraction - i.e. .0285

E_o is the energy utilized in 1965: 50.6×10^{15} BTU

n is the number of years, in this case, 35.

ΣE was calculated to be 2.98×10^{18} BTU or about 3 Q[1]

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[1] Quintillion or 10^{18}.

Table 7

Per Capita Energy Consumption in the United States

1940 - 1965[1]

Year	Energy/Cap. BTU x 10^6
1940	181
1945	238
1950	226
1955	243
1960	249
1965	281

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[1] Gas Facts, 1965, p.22.

Table 8

Efficiency of Energy Conversion by the Electric Utilities

	Per Kw-h		
	Coal-lb.	Oil-gal.	Gas-ft3
1945	1.33	0.109	16.5
1955	0.95	0.085	12.1
1965	0.86	0.075	10.5
Av. %/yr.	2.6	2.3	2.8
%/yr. 1945-55	3.7	2.8	3.6
%/yr. 1955-65	1.0	1.2	1.5

The average annual projected rate of increase, 1965 - 2000, in hydro and nuclear energy was calculated to be 1.6% and 17.7% respectively. By means of equation (1) it was found that the cumulative energy contributions from these sources would be 0.034 Q and 0.46 Q respectively. Thus the calculated breakdown in cumulative energy sources for 1965 - 2000 would be:

Fossil fuels:	2.48 Q
Nuclear:	0.46 Q
Hydro:	0.034 Q

The total calculated quantity, 3 Q, is consistent with published estimates.

Table 9

Estimates of Energy Requirements: 1960 - 2000

	Cumulative Q (1960 - 2000)*
Weeks, 1960	3.9
Searl, 1960	3.7
AEC, 1962	3.4
Dept. of Interior, 1962	
upper middle	3.5
lower middle	3.1

* From Table 3, p.49, Appendices to Civilian Nuclear Power, AEC, 1962.

III.B. Energy Reserves

It is of interest to match estimated cumulative energy requirements with reserves of energy sources both known and suspected in order to evaluate resource adequacy.

The AEC had summarized the available data as of 1962. This information appears in abbreviated form in Table 10 as well as the estimates contained in a more recent report (Hendricks, 1965).

It is immediately apparent that coal and shale oil are in most plentiful supply irrespective of which estimates are used and that the Department of Interior Energy Policy Staff's evaluation of reserves differs radically from those of other sources. The differences are largely ascribable to the quantity considered to be recoverable from marginal sources. Liquid hydrocarbons, which include LPG, is next most plentiful and natural gas is the least plentiful. It is difficult to make a strict comparison between the above estimates, because of differences in terminology. All, of course, contain known, proven reserves, while others contain judgments on undiscovered reserves, known recoverable reserves, known marginal reserves, undiscovered marginal reserves, etc.

Table 10

Estimates of Recoverable Fossil Fuel Resources, Q *

	Coal	Hydro-carbons	Natural Gas	Shale Oil	Total
NAS, Report to the Comm. on Nat. Resources (1962)[1]	22.1	0.6	0.8	4.8	28.3
Nat. Fuels and Energy Study Group (1962)[1]	17.3	2.4	1.3	6.4	27.4
Geol. Survey Bull. 1136 (1961)[1]	17.3	2.3	1.9	4.1	25.6
Energy Policy Staff, Dept. of Interior (1962)[1]	88.6	3.9	2.5	35.1	130.1
Geol. Survey Circular 522 (Hendricks, 1965)	-	2.6	2.0	-	

* Q = 10^{18} BTU

[1] Appendices to Civilian Nuclear Power, AEC, 1962, Table 2, p.5.

Utilizing the three groups of more conservative figures, it is seen that total fossil reserves, proven and unproven, lie in the 25 - 35Q range, that the cumulative demand, 1965 - 2000, could be satisfied by coal or shale oil alone and by neither liquid hydrocarbons nor natural gas alone.

A realistic appraisal indicates a mixed rather than a single fuel economy. It is expected that supply pressures will develop in the coming years, which will tend to raise natural gas prices causing this fuel to lose ground while technological developments coupled with the presence of large deposits is expected to cause coal to increase its share of the market. Tempering these marketplace considerations will be consumer preferences as well as governmental regulations which historically have had their bases in defense-conservation considerations and/or public health (see section on "Policies and Energy Sources"). Thus the Oil Import Agency controls the import of foreign oil, presumably to protect domestic sources, and California permits the burning of fuel oil containing 0.5% or less sulfur in the summer only.

III.C. Future Energy Patterns

The estimates, by various authors, of total energy demand for 1965, 1980 and 2000 appearing in Table 6 have been divided between fossil, nuclear and hydro-energy sources percentage-wise in Table 11. The data is further broken down into fossil fuel categories by percentages in Table 12 and into physical quantities in Table 13.

It is clear from Table 11 that fossil fuels are expected to lose a substantial share of the energy market to nuclear power over the next 35 years, although the combined thermal values and therefore the physical quantities will increase i.e. 0.956 (50.6×10^{15} BTU) in 1965 to 0.784 (136×10^{15} BTU) in 2000. Within the fossil fuel market, coal and oil are expected to show rising trends in their segments, while natural gas will decrease (Table 12) for the reasons stated previously.

The implications for atmospheric pollution are brought out by the data on the quantities of each fuel that will be required in Table 13. Thus petroleum, which includes LPG, and coal use will more than double between 1965 and 1980 while the use of natural gas - the least objectionable from the pollution point of view - will increase by only 60 - 70%.

Table 11

Per Cent Contributions of Primary Energy Sources

1965 energy consumption: 50.6 x 10^{15} BTU
1980 energy consumption: 82.4 x 10^{15} BTU
2000 energy consumption: 136 x 10^{15} BTU

	1965**			1980***			2000***		
	F*	H*	N*	F	H	N	F	H	N
Vogely and Morrison (1966)	95.6	4	0.4	91.5	3.6	4.9			
Lamb (1959)				93.4	2.6	4.0			
Texas East. Trans. (1961)				96.2	2.4	1.4			
Teitelbaum (1958)				88.3	3.0	8.7			
Lasky (1962)				95.0	2.5	2.5			
AEC (1962)				94.0	3.0	3.0	75.0	1.7	23.3
Landsberg (1963)				91.9	3.4	4.7	83.9	2.1	14.0
Sporn (1959)							76.4	2.3	21.3
Clark (1967)				88.6	3.1	8.3			
Mean	95.6	4	0.4	92.9	2.9	4.2	78.4	2.1	19.5
(Mean)[1]				(92.4)	(2.9)	(4.7)			

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* F = fossil fuel; H = hydropower; N = nuclear power.

** Vogely, W. A. and W. E. Morrison, "Pattern of Energy Consumption in the U.S.," World Power Conf., Tokyo, Oct. 1966.

*** Energy R and D and National Progress, Cambel et al. 1966, Table 1-15, p.22 and personal communication from S. H. Clark, Dir. of Energy and Resources Economics, Stanford Res. Inst. Jan. 11, 1967. For a more complete treatment of the nuclear projections see Table 26.

[1] The Clark data was made available too late to be included in the first set of means; the latter was used in pollutant production estimates for 1980.

Table 12

Per Cent* Contributions of Primary Fossil Fuels

	1965			1980			2000		
	Coal	Oil	Gas	Coal	Oil	Gas	Coal	Oil	Gas
Vogely and Morrison (1966)	25.3	41.9	32.8	24.7	43.1	32.2			
Texas Eastern Trans. (1961)				29.2	40.7	30.1			
Teitelbaum (1958)				26.9	47.0	26.1			
Lasky (1962)				27.6	43.4	29.0			
Landsberg (1963)				21.7	45.2	33.1	15.8	54.4	29.8
Sporn (1959)							39.3	40.6	20.1
Mean	25.3	41.9	32.8	26.0	43.9	30.1	27.2	47.6	25.2
Clark, SRI (1967)**				21.5	43.7	34.8			
Mean				25.2	43.9	30.9			

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* Based on thermal contribution by each fuel source.

** The Clark data (1967) for 1980 was submitted after the means of the other five studies had been computed and used as a basis for various other calculations. Hence, two means appear for 1980.

Table 13

Energy and Quantity of Fuel by Source

1965, 1980, 2000

	1965		1980*		2000	
	BTUx10^{15}	**x10^9	BTUx10^{15}	**x10^9	BTUx10^{15}	**x10^9
Nat. Gas	16.0	16,000 ft^3	22.5	22,500 ft^3	26.6	26,600 ft^3
Petroleum Products	20.3	156 gals.	33.4	256 gals.	50.6	386 gals.
Coal	12.3	0.472 tons	20.1	0.77 tons	28.8	1.11 tons
Total Fossil Fuel	48.6		76.0		106.0	
Nuclear and Hydro	2.0		5.8		30.0	
Total Energy	50.6		81.8		136.0	

* Computed without the data submitted by Clark, SRI, 1967; see Tables 11, 12.

** Calculated @ 1000 BTU/ft^3 gas, 1.31x10^5 BTU/gal. of petroleum products, and 13,000 BTU/lb of coal.

The above data was computed from Tables 6, 11, 12.

IV. National Production of Pollutants by Fossil Fuels: 1980 and 2000

We are now in a position to calculate pollution loads for the nation as a whole and for specific SMSA's or urban consolidated areas. Utilizing the mean data for 1980 and 2000 in Tables 11 and 12, national mean daily production was calculated for these years with respect to individual pollutants from gas, oil and coal (Tables 14 and 15). Similar data for 1965 was discussed earlier and appears in Table 5. These data can only be regarded as representative since combustion product yield, especially from coal, is highly dependent on the source and nature of the fuel as well as the efficiency of the combustion unit. Additionally, as was pointed out previously, the original energy estimates as well as the energy distribution patterns for 1980 and 2000, both of which affect the pollutant production load, are subject to significant uncertainties.

The data on combustion product yields which appear in Table 5, 14 and 15 are summarized in Table 16 and further, in the latter Table the contaminants are ranked with respect to weight for the three bench-mark years.

Among the volatile combustion products of fossil fuels, CO, hydrocarbons, SO_x and NO_x are and probably will continue to be produced in that order by weight. As is indicated by the data for SO_2 in Tables 5, 14 and 15, it is produced almost exclusively by coal and petroleum products with the former emitting 5-6 times as much as the latter in each of the three selected years. The total quantity of SO_2 generated in future years is expected to increase slightly faster than total fossil fuel demand because coal and oil will take a somewhat larger share of the fossil fuel market (Table 12). The data also indicates that by 2000, the production rate of SO_2 will be somewhat more than double that of 1965 and that there will be little change in the relative contributions by oil and coal to the total (Tables 5, 14, 15). These estimates of SO_2 production in Tables 5, 14, and 15 are in excellent agreement with those of F. Rohrman[1]. Thus oil and coal will continue to supply about 15% and 80% of the total SO_2 production respectively. This ratio is, of course, dependent on the assumed national mean sulfur content of the fuel source. For purposes of calculation, a 2% value had been assumed for coal, 1.6% for residual oil and 0.43% for oil distillate. Even if it was assumed that the sulfur content of coal could be reduced to 1%, it would still continue to be the principal source of SO_x. It would appear that both coal and oil should be and should continue to be prime targets on a national scale for the abatement of SO_2 production.

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[1] Rohrman, F. A., B. J. Steigerwald and J. H. Ludwig, "The Role of Power Plants in Sulfur Dioxide Emissions: 1940 - 2000" Table I, unpublished.

Table 14

Estimated Daily Pollutant Production From Fossil Fuels - 1980

National Production

	lbs/day - 1980				
	Petroleum Prod.		Natural		
	Gasoline	Fuel Oil	Gas	Coal	Total
CO x 10^6	1410 *	0.208	0.017	1.04 to 104	1411 to 1514
Hydrocarbons x 10^6	254	0.346	neglig.	0.415 to 20.8	255 to 276
SO_x x 10^6	4.35	31.8	0.0252	157	193
NO_x x 10^6	54.6	17.9	15.9	33.2	122
Organic Acids x 10^6	1.93	n.a.**	3.88	n.a.	5.81
Aldehydes x 10^4	194	26.5	6.26	1.04	227
NH_3 x 10^4	96.6	n.a.	1.9	n.a.	98.5
Benzo(a)pyrene	331	10.1	9.2	2.7 to 54,600	353 to 54,900
Particulates x 10^6	5.32	2.04	1.06	39.4 to 394	47.8 to 402
Total x 10^6	1532	52.5	21.0	231.0 to 518.9	2038 to 2516

* Principal producer of effluent substance is underscored.

** n.a.: not available.

See Table 5 for footnotes.

Table 15

Estimated Daily Pollutant Production From Fossil Fuels - Year 2000

	lbs/day - year 2000				
	Petroleum Prod.				
	Gasoline	Fuel Oil	Natural Gas	Coal	Total
CO x 10^6	2280 *	0.236	0.0199	1.52 to 152.2	2282 to 2432
Hydrocarbons x 10^6	441	0.394	neglig.	0.609 to 30.6	442 to 473
SO_x x 10^6	7.06	36.9	0.0294	232	276.1
NO_x x 10^6	88.5	20.4	18.7	49.0	176.6
Organic Acids x 10^6	3.13	n.a.**	4.55	n.a.	7.68
Aldehydes x 10^4	313	29.8	7.34	1.53	352
NH_3 x 10^4	156	n.a.	2.20	n.a.	158
Benzo(a)pyrene	519	115	9.2	4.0 to 80,600	647 to 81,2
Particulates x 10^6	8.61	2.32	1.25	58.1 to 581	70.3 to 593
Total x 10^6	2262	60.55	24.64	341.2 to 1046	3259 to 396

* Principal producer of effluent substance is underscored.

** n.a.: not available.

See Table 5 for footnotes.

Table 16

Estimated Total Daily Pollutant Production From Fossil Fuels

1965, 1980, 2000

National Production

Fossil fuel demand: 1965 - 133 x 10^{12} BTU/day
1980 - 208 x 10^{12} BTU/day
2000 - 292 x 10^{12} BTU/day

	lbs/day in rank order		
	1965	1980	2000
CO x 10^6	791 to 854	1411 to 1514	2282 to 2432
Hydrocarbons x 10^6	142 to 155	255 to 276	442 to 473
SO_x x 10^6	121	193	276
NO_x x 10^6	75	122	177
Organic Acids x 10^6	3.78	5.81	7.68
Aldehydes x 10^6	1.28	2.27	3.52
NH_3 x 10^6	0.557	0.985	1.58
Benzo(a)pyrene	194 to 34,000	353 to 54,900	647 to 81,243
Particulates x 10^6	29.6 to 249	47.8 to 402	70.3 to 593

See Table 5 for footnotes.

NO_x is produced largely from the combination of the constituents of air in the presence of high temperatures. Thus it is produced by any combustion device; its rate of production is largely a function of the characteristics of the burner, the combustion temperature and the substance oxidized. Gas burners appear to be particularly sensitive to these factors for M. Mayer (1965) lists 116 lbs of NO_x per 10^6 ft3 of natural gas for domestic and commercial heating units and 390 lbs. for power plants. The same author shows only 72 lbs. of NO_x per 1000 gal. of oil for 1000 h.p. or less and 104 lbs. for 1000 h.p. or more. Mayer also reported mean values of 0.67 lbs. NO_x per 10^6 BTU from oil, 0.61 lbs. from coal and only 0.26 lbs. from gas. This low NO_x ratio per unit of energy for gas explains in large measure the lower production in 1965 and 1980 in spite of its higher usage than coal in those years (Table 13). Conversely, petroleum products, especially the lower boiling fractions, are the highest producers in each of those years although the discrepancy between the NO_x production of each fossil fuel is not remarkable. Any measures applied to NO_x reduction should be directed at all three fossil fuels.

CO production is expected to increase by a factor of about three: from about 800 million pounds per day to about 2300 million pounds per day in the next 35 years. Inspection of the CO data in Tables 5, 14 and 15 reveals that the greatest producer by far of CO in 1965 and the greatest producer in the future will be the lighter fraction of petroleum products. This follows from the large volumes oxidized as well as the high ratio of CO per unit of energy. Thus, these products produce about 22 x 10^{-6} lbs/BTU while coal only yields $(0.02 \text{ to } 1.9)^{-6}$ lbs/BTU. Natural gas is such a minor producer of CO (less than 0.002%) that it can be neglected for purposes of control. To identify the source more concisely: a minimum or 92% of all CO produced originated in the lighter petroleum fractions in 1965 and will increase to at least 94% by 2000. At that time, if the daily production of CO were restricted to 3 meters from the ground, an average concentration of 33 ppm over the whole nation would result; the MPC for CO is 33 ppm[1]. Thus it is quite obvious where the chief target for CO control lies and where it will probably lie in the future.

Analysis of the data for trends in hydrocarbon production reveals essentially the same prognostication. Total production will triple between 1965 and 2000 (Table 16). Natural gas produced negligible quantities of these compounds while the low boiling fractions of petroleum produced the most in 1965 and are expected to continue doing so: they produced at least 91% in 1965 and can be expected to maintain this level i.e. 92% and 93% in 1980 and 2000 respectively.

[1] California standard; 8 hour averaging time.

Benzo(a)pyrene is a known carcinogenic agent which is emitted over a wide range of concentrations from coal, depending upon the type of unit involved. Thus Mayer (1965) reports that the unit utilizing pulverized coal and the spreader stoker emit 600 and 700 ug/ton of coal while, at the other extreme, the hand-fired stoker emits about 12 x 10^6 ug/ton. Therefore, in 1965, the total emission of this compound lay in the range of 10,000 to 12 million pounds. Most hand-operated units are used for domestic heating. An interpolated figure from Landsberg[1] shows that only 3.4% of total coal consumption occurred in residential units. Hence, the true benzo(a)pyrene production probably lies at the lower end of the scale. It seems probable from the data that coal and oil are the principal sources of this carcinogen although the combustion of natural gas results in the emission of small but possibly physiologically significant amounts (Tables 5, 14 and 15). As was the case with the previously discussed compounds, total poundage of this potent combustion product will more than triple in the next 35 years.

Data on the emission of organic acids and NH_3 from oil and coal were not available so that the estimates appearing in Tables 5, 14, 15 and 16 refer only to the more volatile fractions of petroleum products and natural gas. Petroleum products are the principal sources of ammonia while both gas and petroleum

[1] Landsberg, "Resources in America's Future" 1963, A15-16, p.854.

are prime sources of organic acids. These relationships are not significantly altered between 1965 and 2000 although their production will increase by factors of 2-3.

In 1965, aldehydes originated almost exclusively in petroleum products - better than 99%, of which about 85% came from the low-boiling fraction - and they are expected to continue to do so in the foreseeable future.

Particulate emission represents a special case. Emission factors for gas and oil vary little with the size and type of unit but they are strongly dependent on the type of combustion unit in which coal is burned as well as the ash residue of the coal. Thus, if a cyclone unit is used, the particulate production is (2 lbs/ton)A where A is the per cent of ash, while a spreader stoker will permit a yield of (20 lbs/ton)A. W. S. Smith (1962) reported 4-15% by weight of ash for bituminous coal. Since the bituminous/anthracite ratio in 1965 was about 22.1/0.7[1] this percentage figure for ash is representative for the coal industry. Therefore, the ash from coal will vary from 8 to 300 lbs/ton. In making the calculations for the data that appear in Tables 5, 14 and 15, a mean ash value of 9.5% and consequently 19 and 190 lbs/ton were used. Examination of the data in Tables 5, 14 and 15 leads to the conclusion that coal has been and will continue to be the source of at least 80% of the particulates generated by fossil fuels and that by the year 2000, the total weight produced per day will have increased by at least 100% (Table 16).

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[1] Gas Facts, 1965, p.20.

The above analysis has been based upon yields of contaminants in terms of their weight without regard to their relative biological effects. However, in evaluating general physiological and pulmonary hazards one must give due emphasis to (a) the physiological response per unit weight of contaminant and (b) the residual effect. For example, the effects of CO are completely reversible provided exposure has been sufficiently limited to prevent damage to the central nervous system while the effects of benzo(a)pyrene, a potent carcinogen are not reversible. Hence, it is quite clear that in order to evaluate more fully the effect of atmospheric contaminants, it is necessary not only to relate them to "Maximum Permissible Concentrations" but these in turn should take into account the above specified considerations.

V. Application of Pollution Projections to Large Urban Populations

The data discussed above refers to national trends pertaining to total projected energy demands and patterns of energy sources. It does not yield any data that can be translated into pollutant concentrations in urban atmospheres either present or future. One can attempt to do this in either of two ways. (a) The emission rate for specific pollutants is estimated and by assuming an infinite number of constant emitters spread evenly over a finite urban area as well as specific meteorological conditions, the average concentration at a height of 6 ft. is calculated and (b) future mean atmospheric concentrations are estimated by extrapolation from known correlations between pollutant production rates and measured atmospheric concentrations. In view of time and man-power limitations the second method was selected.

In order to make urban atmospheric pollution projections, the rate of population increase for the three largest metropolitan areas, the New York Consolidated Area, the Chicago Consolidated Area, and Los Angeles County was calculated for the period 1960 - 1965. In making these calculations, it was observed that the rate of population increase in these urban areas was substantially lower than those of the states of which they are a part. Thus:

Table 17

Annual Population Increase in Selected States and Urban Areas

Urban Area	%/yr. Increase 1960-65	States	%/yr. Increase 1960-65
New York	1.34	N. Y.-N. J.	1.67
Chicago	0.14	Ill.-Indiana	1.59
Los Angeles	2.43	California	4.10

Therefore, in making the population projections for the years 1980 and 2000 for these urban areas (Table 18), the urban-specific data was used.

Table 18

Population Projections to 1980 and 2000 for the Three Largest Urban Areas*

	Population x 10^3		
	1965	1980	2000
New York Consolidated Area	15,747	19,265	25,090
Chicago Consolidated Area	7,230	7,384	7,594
County of Los Angeles	6,776	9,714	15,704

* As defined by the Bureau of Census, Department of Commerce.

Energy demand projections for the above statistical areas were approximated in the following manner. Fuel consumption in the states of which the statistical areas are a part, for coal, natural gas and petroleum products for 1964 - 65 were obtained[1] and converted to thermal energy units. The fraction of total energy contributed by each fossil fuel was calculated (1965) and was then adjusted to reflect the trends for 1980 and 2000 appearing in Table 12. Next the per capita energy demand in 1965 for the states concerned i.e. New York-New Jersey, Illinois-Indiana, California, was calculated and these data were adjusted in accordance with the national projections appearing in Table 6. Knowing the population, fossil fuel demands per capita and percentage distribution of each fuel as a function of time, the BTU demands were calculated. These data appear in Table 19. Of course, such estimations are based upon a number of assumptions, any one of which could alter the data radically. Some of these assumptions are: There will be no major international conflicts of any significant dimensions; a growth rate in population of the statistical areas that is constant over the 1960 - 2000 time span (Table 17); adequate supplies of fossil fuel resources, domestic and foreign; no major break-throughs in the technology of use of any fossil fuel[1]; no other energy source (solar, MHD, shale oil, etc.) except nuclear power will significantly contribute to total energy demand; control of atmospheric pollution will not be achieved by restricting combustion of fossil fuels. Other assumptions are: The energy demand per capita in the urban area and the surrounding state(s) are the same and the change in pattern of use of the fossil fuel will correspond to the changes in national use patterns.

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[1] Natural Gas- Gas Facts, AGA, 1965, p.98.

Coal- Minerals Yearbook, U. S. Bureau of Mines, 1965, pp. 140, 196.

Petroleum products (residual and distilled oil, gasoline, kerosene, LPG)- Petroleum Facts and Figures, API, 1965, pp. 167, 194, 208, 215.

It is apparent from the data in Tables 18 and 19 that, of the three statistical areas, Los Angeles is the fastest growing while Chicago is growing very slowly. Consequently, between 1965 and 2000, Los Angeles will displace Chicago as the second largest metropolitan area. On the other hand, Chicago has the highest per capita consumption of fossil fuel energy, primarily because of the large amounts of coal consumed - presumably most of it goes to the steel mills of Gary and East Chicago.

The important factors to consider in assessing present and future atmospheric loads over urban areas is the qualitative and quantitative aspects of the pollutants, the area over which they are disseminated and the characteristic meteorological conditions.

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[1] This is a highly speculative assumption as is brought out later in this report.

Table 19

Estimated Consumption of Fossil Fuels in Three Metropolitan Areas: 1965, 1980, 2000

New York Consol. Area	1965		1980		2000	
Population x 10^6	15.747		19.265		25.090	
(BTU/cap)10^6	174		218		271	
Total energy -BTUx10^{12}	2740.0		4199.8		6799.4	
Coal -BTUx10^{12}	611.0	(22.3%)	966.0	(23.0%)	1645	(24.2%)
Oil -BTUx10^{12}	1704.3	(62.2%)	2696	(64.2%)	4617	(67.9%)
Gas -BTUx10^{12}	424.7	(15.5%)	537.6	(12.8%)	537.2	(7.9%)

Chicago Consol. Area	1965		1980		2000	
Population x 10^6	7.230		7.384		7.594	
(BTU/cap)10^6	288		360		449	
Total energy -BTUx10^{12}	2082.2		2658.2		3409.7	
Coal -BTUx10^{12}	937.0	(45.0%)	1214.8	(45.7%)	1599.2	(46.9%)
Oil -BTUx10^{12}	639.2	(30.7%)	869.2	(32.7%)	1241.1	(36.4%)
Gas -BTUx10^{12}	506.0	(24.3%)	574.2	(21.6%)	569.4	(16.7%)

Los Angeles County	1965		1980		2000	
Population x 10^6	6.776		9.714		15.704	
(BTU/cap)10^6	171		213		267	
Total energy -BTUx10^{12}	1115.9		2069.1		4193.0	
Coal -BTUx10^{12}	none	(-)	none	(-)	none	(-)
Oil -BTUx10^{12}	553.5	(49.6%)	1073.8	(51.9%)	2356.4	(56.2%)
Gas -BTUx10^{12}	562.4	(50.4%)	995.2	(48.1%)	1836.5	(43.8%)

Table 20

Production of Selected Combustion Products

Chicago Consolidated Metropolitan Area

lbs x 10^6

	Coal*	Petroleum		Nat. Gas	Total
		Gasoline Naphthas etc.	Oil**		
1965					
CO	18-1802	8582	.077-3.84	0.137	8600-10,388
Hydrocarbons	7-360	1542	3.26	neglig.	1555-1909
SO_x	4108	26	286	0.202	4623
NO_x	288-721	333	169	129	919-1352
Particulates	685-6847	32	1.92	8.60	728-6890
1980					
CO	23-2336	11,675	.104-5.22	0.155	11,698-14,016
Hydrocarbons	9-467	2102	4.45	neglig.	2115-2573
SO_x	5326	36	388	0.230	5750
NO_x	373-934	453	230	146	1203-1763
Particulates	888-8877	44	26	9.76	968-8957
2000					
CO	31-3075	16,700	15-746	0.154	16,746-20,521
Hydrocarbons	12-615	3003	6.34	neglig.	3051-3654
SO_x	7012	52	555	0.228	7619
NO_x	492-1230	648	328	145	1613-2350
Particulates	1169-11,687	63	37	9.68	1279-11,796

* 3% sulfur per Dr. F. Rohrman, PHS, private communication.

** Residual oil fraction: 33% of total; average sulfur content, 2% for Chicago per Dr. F. Rohrman, PHS. Distillate oil was assumed to contain 0.43% sulfur per "Atmospheric Emission From Fuel Oil Combustion," W. S. Smith, USPHS, 1962.

There is a continuing highly sophisticated effort by an ESSA group[1] assigned to the PHS, Cincinnati, to translate these factors into atmospheric concentrations (Pooler, 1961; Clark, 1963; Turner, 1964; Miller, 1966). For the purpose of scoping the problem, the production (in contradistinction to emission) of those pollutants in Chicago, for which annual and maximum concentration data are available, was estimated for 1965, 1980 and 2000. These data appear as Table 20; principal sources are underlined and are listed percentage wise as follows:

Table 21

Principal Sources of Combustion Products

Chicago: 1965 - 2000

	Per Cent: 1965 - 2000			
	Coal	Gasoline Naphthas etc.	Oil	Nat. Gas
CO		80-99		
Hydrocarbons		80-99		
SO_x	89-93			
NO_x	30-53	24-40	12-20	6-14
Particulates	91-99			

It is clear that coal is the prime producer of SO_x and particulates and is a source of substantial amounts of NO_x; the low boiling fractions of crude oil, gasoline, naphthas, kerosene etc. are the principal origins of CO and hydrocarbons while producing about the same amount of NO_x as does coal.

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[1] Formerly U. S. Weather Bureau Research Station.

In Table 20, many of the annual production figures appear as ranges rather than specific numbers primarily because the quantity of these compounds produced is heavily dependent upon the kind of equipment used, especially in the case of coal[1]. Thus, a similar computation for Los Angeles, which burns no coal, would result in more precise - though possibly not more accurate - data.

The measured average annual and average maximum atmospheric concentrations[2], which are the direct result of the annual pollution loads calculated for 1965, appear in Table 22. These data are important in that they permit an extrapolation to be made for future years with respect to expected atmospheric concentrations on the basis of estimated future annual pollutant production. This was done for the years 1980 and 2000, using as a base the assumptions previously identified as well as the assumption that fuel and pollution abatement policies, public and private, will not be significantly different from those in existence in 1965. In view of the present ferment about pollution, this last assumption is highly debatable. Obviously in making projections one cannot draw too stringent a parallel between urban, state, and national projections. However, in this case, where there are so many variables with poorly defined limits, these assumptions are believed to be acceptable for present purposes.

[1] Computation of national daily atmospheric pollution loads gave similar ranges; see Tables 5, 14, and 15.

[2] Acceptable corresponding data for New York and Los Angeles are not available.

Table 22

Projection of Pollutant Atmospheric Concentrations Over Chicago

1980 and 2000

	1965			1980				2000			
		Atmos. Conc.*									
Pollutants[a]	Ann. Prod. lbs x 10^8	av. ppm	max. ppm	Ann. Prod. lbs x 10^8	Constant Area[b] av. ppm	Constant Popul. Density[c] av. ppm	Max. ppm	Ann. Prod. lbs x 10^8	Constant Area[b] av. ppm	Constant Popul. Density[c] av. ppm	Max. ppm
CO	86.0-104.0	32	59	117-140	44-52	43-51	80	167-205	62-76	59-72	115
Hydrocarbons	15.6-19.1	2.6	10.0	21.0-26.0	3.5-4.3	3.4-4.2	13.5	30.5-36.5	5.1-5.9	4.8-5.6	19.3
SO_x	46.2	0.13	1.14	57.5	0.16	0.16	1.42	76.2	0.22	0.21	1.88
NO_x	9.20-13.5	0.04	0.18	12.0-17.6	0.05-0.08	0.05-0.08	0.23	16.1-23.5	0.07-0.10	0.07-0.10	0.31
Particulates**	7.30-68.9	ug/m^3 140	ug/m^3 244	9.70-89.6	ug/m^3 186-1720	ug/m^3 182-1680	ug/m^3 318	12.8-118	ug/m^3 245-2270	ug/m^3 233-2160	ug/m^3 419

* Four year summary of the data from the CAMP Program, USPHS, Cincinnati, August 1966. The "av." column contains annual averages based on 12 monthly averages. The "max." data refers to an annual average of those 1 hr. samples showing maximum values.

** Air Quality Data, 1964-65, USPHS, Cincinnati, 1966.

(a) Mean annual atmospheric concentrations for the other pollutants listed in Tables 5, 14, and 15 not available.

(b) The increase in population occurring 1965-1980 and 1965-2000 was assumed to occur within the Standard Consolidated Area as defined in 1965.

(c) The population density was assumed to remain unchanged between 1965 and 2000 thus increasing the Standard Consolidated Area proportionately.

On the basis of expected annual pollutant production in 1980, the average annual atmospheric concentration of the gaseous products listed, with the exception of SO_x, can be expected to increase about 50% over 1965 (Table 22). Apparently, it matters little whether a constant urban area (Column b) or a constant population density (Column c) are assumed because of the extremely slow growth rate of the Chicago Consolidated Area.

The average annual SO_x atmospheric concentration will increase about 25%, roughly paralleling the increased demand for coal which supplies about 90% of this contaminant in the Chicago area.

An increase between 30% and 1100%, in the atmospheric concentration of particulates can be expected since coal also is the prime source of this substance in Chicago. The wide range quoted merely indicates that particulate emission can vary by more than an order of magnitude depending on the equipment used (Mayer, 1965)*. Keeping in mind the caveat that these estimates are based on maintaining the same degree of emission control as exists in 1965, a reasonable guesstimate is that its increase in annual average concentration will parallel that of coal and SO_x - about 25%.

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* Since most coal burning equipment today is of substantial size and particulate production is an inverse function of size, the emission of particulates will probably be in the lower end of the range quoted.

Turning to the year 2000 data, a factor of two applies to the CO, hydrocarbons and NO_x when compared with 1965. Also, SO_x can be expected to increase by about 70% and particulate concentrations by about the same amount. The ratio of the average one hour maximum concentrations to the average annual level varied, in 1965, from about 1.7 for particulates to approximately 9 for SO_x. Assuming these maximum 1 hr./annual ratios are applicable to 1980 and 2000, the maximum one hour atmospheric concentrations were calculated. A comparison was then made with a list of air quality standards from various sources (Table 23).

It is evident that (1) air quality standards for many of the pollutants appearing in Table 5 or even the truncated list in Table 20 are non-existent, (2) that the standards vary with the political entity and (3) that the measuring times also vary but are relatively short: instantaneous to 24 hours. Referring to Tables 20 and 22, it is clear that the Chicago CO level is 1965 is well within the California standard, but greatly exceeds the USSR permissible level. If the California standard is the criterion, CO will not be a major problem in Chicago until about 2000.

The only NO_2 air quality standard is that of West Germany which is based on an averaging time of 0.5 hour. Assuming that a one hour sample probably would not differ radically, it would appear that Chicago need not be concerned about this compound even beyond 2000.

Table 23

Air Quality Standards for Various Pollutants

	Averaging Time-hrs.	% of Time Stand. can be Exceeded	ppm		
			CO	NO_2	SO_2
California	1		120		1
	8		30		0.3
Colorado	1	1% in 3 months			0.5
	24	1% in 3 months			0.1
Los Angeles	instant				3.0-1st alert 5.0-2nd alert 10.0-3rd alert
PHS	24	exceeded not more than 1 day in 100 consecutive days			.02-ann. avg. .10
	1	exceeded not more than 1 hr. in 4 consecutive days			.25
	1/12	exceeded not more than 5 min. in 8 consecutive hours			.50
Manitoba, Can.	1				1.0
	8				0.3
W. German	1/2			0.5	0.2
U. S. S. R.	1/3		4.8		0.18
	24		0.8		0.06
Poland	1/4				0.31
Rumania	24				0.09

There is a plethora of standards for SO_2; Table 23 contains only a partial list. If standards per pollutant is any criterion, SO_2 is generally considered to be the primary target for atmospheric pollution control - although the basis for such a pre-eminent position has not been firmly established in terms of relative physiological effects. Using the most stringent value among the one-hour limits, the PHS standard of 0.25 ppm, it is seen that Chicago has already exceeded this level by more than a factor of four in 1965 and by 2000 will have exceeded it by a factor of about 7-1/2.

From the data in Tables 19 and 20, it was calculated that the ratio of SO_2 production in pounds to the energy demand (excluding natural gas), in 1965 was 2.9 lbs/10^6 BTU; in 1980 and 2000, it will be 2.8 and 2.7 lbs/10^6 BTU respectively. For these same years, the maximum average concentration (1 hr. averaging time) listed in Table 22 is 1.14 ppm, 1.42 ppm and 1.88 ppm. On the basis of the PHS air quality standard of 0.25 ppm for a 1 hour averaging time, therefore, the maximum permissible emission rates should be:

Chicago		lbs.SO_2/10^6 BTU
1965	(0.25/1.14)2.9 or	0.64
1980	(0.25/1.42)2.8 or	0.49
2000	(0.25/1.88)2.7 or	0.36

The calculated emission rate for 1965 is in excellent agreement with the maximum emission rate proposed by H.E.W., which appeared in the Federal Register*: 0.65 lbs. $SO_2/10^6$ BTU. If the projected energy requirements are reasonably correct, this maximum emission rate will have to be reduced by 23% in 1980 and again by 26% in the year 2000.

As a practical matter, emission standards should be reduced periodically to keep pace with continuously rising atmospheric levels. If one accepts the above projected maximum emission rates, then from the relationship $(1-R)^n = P/P_o$ in which R is the annual fractional decrement in emission rate, and P_o and P are the initial and final emission rates, between 1965 and 1980 the maximum emission rate should be decreased by 0.016 lbs. $SO_2/10^6$ BTU/yr; similarly, between 1980 and 2000 it should be decreased 0.020 lbs. $SO_2/10^6$ BTU/yr.

In order to reduce atmospheric concentrations of SO_2 to acceptable levels, the emission maximum of 0.64 lbs. of $SO_2/10^6$ BTU should be applied to all consumers of sulfur-rich fuel. Further, such an emission standard corresponds to coal and residual oil containing 0.4% and 0.6% sulfur respectively. Since very little coal and residual oil that meet these qualifications are available, the application of these standards to Chicago as a whole would effectively prohibit the use of these fossil fuels in Chicago.

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* Vol. 31, No. 226, Nov. 22, 1966.

Obviously, on the basis of present and expected atmospheric concentrations of SO_2, drastic action in the way of fuel modification and/or substitution is required to not only keep up with an expanding economy and population, but also to reduce it below present levels.

VI. Energy Demand and Production of Pollutants by Sectors: 1965 - 2000

A. Projections of Energy Demand and Pollutant Production by All Sectors Except the Electrical Utility Industry

For purposes of abatement, it is important to identify those sectors of the economy that will be major contributors to atmospheric pollution in the future. In making such an analysis, one must keep in mind that such projections are based upon those market conditions that apply in 1963 - 65 and that no allowance is made for restrictions that could be applied by governments at the national, state or local levels for reasons of defense, conservation, health, wars, new political realignments, etc.

These sector data have been collected in Table 24; the two sources are Vogely and Morrison (1966) and Landsberg (RFF, 1963). The data have been converted to percentages in Table 25 using the Vogely estimates for 1965, the Vogely and RFF figures for 1980 and RFF alone for 2000.

Examination of Table 24 discloses several cases of substantial differences between estimates from the two sources; this makes it difficult to establish trends. However, it is clear that the industrial sector as a whole will increase its energy requirements substantially in the period 1965 - 2000, but its share of the total energy market will change little (Table 25). Most of the increased energy demand in this sector will fall to oil and gas. The use of coal will grow slowly, perhaps reflecting the increased needs of the metallurgical industry, its prime customer in this sector. Therefore, in combating pollution from industrial sources, the contribution from all three fuels is so substantial that attention must be directed at minimizing (a) the present production from coal, oil and gas and (b) the anticipated increased production from oil and gas.

In the field of transportation, only petroleum products will show a substantial gain - by about a factor of three - but the gain is large enough to permit this sector to increase its share of the total energy demand from about 25% in 1965 to about 31% in 2000. Most of this increase in volume of petroleum products - about 50% in the 1965 - 80 time period and almost 100% in the 1980 - 2000 time span - will most probably occur as a result of further proliferation of the internal combustion engine. A technological break-through in the development of batteries, fuel cells, or steam propulsion could radically alter the projected use of this energy source and, as a consequence, the air pollution problem.

The data on the "Household and Commercial" sector is somewhat indeterminate in that Vogely predicts an increase of about 60% between 1965 and 1980 while the RFF data shows essentially no change. This disparity is more apparent than real: in general the RFF projections tend to be lower than the Vogely data. Actually, an interpolation of the RFF data shows a gain from

9250 x 10^{12} BTU in 1965 to 11,830 x 10^{12} BTU in 1980. Again RFF shows a small gain in total demand for this sector between 1980 and 2000. However, both sets of estimates are in agreement that coal will continue its downward trend, that oil will make modest gains, while gas will make its largest gain between 1965 and 1980. Thus, oil and coal are not expected to keep up with the growth of the total energy market in this sector (Table 25); even gas may lose ground percentage-wise in the 1980 - 2000 time-frame.

Comparing the growth in population between 1980 and 2000 - 32% - with the increased energy demand for the "Household and Commercial" sector projected by RFF, 6.5%, it appears that a substitute source of energy will be employed. The most likely one, electrical, will be examined below. So far as atmospheric pollution from this sector is concerned, oil and gas are the only sources of any consequence; with respect to increased pollution, it will come primarily from gas, the least objectionable of the three fossil fuels.

It is concluded that the use of fossil fuels in the "Household and Commercial" sector probably will not radically alter the quality of air in the foreseeable future.

Table 24

Energy Demand by Sectors for 1965* and the Projected Demand for 1980* and 2000

The 1965 data is preliminary; ( ) represents RFF medium projections made in 1963.

	BTU x 10^{12}					
	Coal	Petrol. Prod.**	Gas	Hydro	Nuclear	Total
Household and Commercial						
1965	539.6	4313	5710	-	-	10,563
						(9250)
1980	325	5722	9999	-	-	16,046
	(520)	(4070)	(7240)			(11,830)
2000	(200)	(4750)	(7650)	-	-	(12,600)
Industrial						
1965	5551	2992	7428	-	-	15,971
1980	5773	4242	11,780	-	-	21,795
	(4430)	(4950)	(9640)			(19,020)
2000	(5760)	(11,450)	(18,000)	-	-	(35,210)
Transport						
1965	19.8	12,297	504	-	-	12,821
1980	neglig.	20,979	698	-	-	21,677
		(17,820)	(710)			(18,530)
2000	neglig.	(36,190)	(1000)	-	-	(37,190)
Electricity						
1965	6043	627	2381	1901	35.7	10,988
1980	13,440	861	2976	3028	4078	24,380
	(9770)	(790)	(3856)	(2640)	(3720)	(20,770)
2000	(10,950)	(860)	(3480)	(2820)	(18,900)	(37,010)
Miscell.	159	865	579	-	-	1603
Total						
1965						51,946
1980						83,898
						(70,150)
2000						(122,010)

* Source: Vogely and Morrison, 1966; data adjusted to eliminate non-combustible petroleum products such as waxes, road oils, etc.

** Includes NGL.

Table 25

Energy Distribution by Sectors: 1965, 1980, 2000

Percentages*

	Per Cent					
	Coal	Petrol. Prod.	Gas	Hydro	Nuclear	Total
Household and Commercial						
1965	1.0	8.3	11.0	-	-	20.3
1980	0.4	6.8	11.9	-	-	19.1
	(0.8)	(5.8)	(10.3)			(16.9)
2000	(0.4)	(3.9)	(6.3)	-	-	(10.6)
Industrial						
1965	10.7	5.8	14.3	-	-	30.8
1980	6.9	5.1	14.0	-	-	26.0
	(6.6)	(7.1)	(13.4)			(27.1)
2000	(4.4)	(9.6)	(14.8)	-	-	(28.8)
Transport						
1965	.04	23.7	1.0	-	-	24.7
1980	neglig.	25.0	0.9	-	-	25.9
		(25.4)	(1.0)			(26.4)
2000	neglig.	(29.6)	(0.8)	-	-	(30.4)
Electricity						
1965	11.6	1.2	4.6	3.7	.07	21.1
1980	16.0	1.0	3.5	3.6	4.9	29.0
	(13.9)	(1.1)	(5.5)	(3.8)	(5.3)	(29.6)
2000	(9.0)	(0.5)	(2.9)	(2.3)	(15.5)	(30.2)
Miscell.	0.3	1.7	1.1	-	-	3.1

* The percentages in ( ) were derived from RFF "medium" projections made in 1963; the remaining data was derived from Vogely and Morrison, 1966. See Table 24 for the above data expressed as BTU's.

VI.B. Projections of Energy Demand and Pollutant Production by the Electrical Utility Industry

Electrical power production, the only consumer of all five forms of basic energy, is a special case in that it has been the object of detailed analyses and projections not only by the sources identified in Table 25, but also by the Federal Power Commission, the Edison Electric Institute, various large companies, the Atomic Energy Commission etc. The data under the heading "Electricity" in Table 25 has been expanded in Table 26 to include the data from these additional sources.

The data suggests that (1) the use of coal, oil, gas and hydro-power for electrical generation will increase until the 1980 period although the estimates do cover a wide range. However, discounting for the moment the 1962 AEC estimate for the year 2000, their growth will slow down drastically at that time and they will be at substantially the same level when the year 2000 is reached (2) the thermal energy from coal will continue to be about twice that from oil, gas and hydro-power combined (3) nuclear power will demonstrate a spectacular rise in the 1965 - 2000 period - this accounts for the essentially static energy demands from the fossil fuel and hydro-power after 1980 and (4) the electrical energy generated from nuclear fuel will substantially exceed that from coal by 2000.

Table 26

Production of Electricity by Source: Statistics for 1965 And Projections for 1980 and 2000

	BTU x 10^{12}					
	Coal	Oil	Gas	Hydro	Nuclear	Total
1965						
Vogely '66	6043	627	2381	1901	36	10,988
1980						
Vogely '66	13,440	861	2976	3028	4078	24,380
Edison Elect. Inst. '66					6374-6840*	
Gen. Elect. '66					7300*	
Westinghouse '66					8760*	
Nat. Power Survey '64	11,250*	952*	4076*	3026*	4575*	23,879
RFF '63	9770	790	3850	2640	3720	20,770
AEC '62	← 23,082 →				2345*	25,427*
AEC '64					3508-5262*	
AEC '66 (Seaborg)					4666-6420*	
AEC '67	← 18,198* →				5550*	21,398-26,688*
2000						
RFF '63	10,950	860	3480	2820	18,900	37,010
AEC '62	← 31,086* →				31,086*	62,176*
AEC '67	← 26,029* →				33,317	41,472-69,123*

All Resources For the Future data are "medium" projections.

* Heat rate: 1980-2243 Kg-Cal/KW-hr. based on rate projected for coal by Vogely, U. S. Bureau of Mines.
2000-1741 Kg-Cal/KW-hr. based on extrapolation of 1980 heat rate.

Load factor of 0.75 assumed where appropriate.

Certain aspects of the nuclear energy projections are worthy of special comment. Following its 1962 report, the AEC revised its estimates of energy demand from nuclear power for 1980 on at least two occasions - each time increasing the level. Thus in 1964 it raised its 1962 estimate for the year 1980 from 2345×10^{12} BTU to $(3508 \text{ to } 5262)10^{12}$ BTU*. Again in 1966 it raised its estimate for 1980 to $(4666 \text{ to } 6420)10^{12}$ BTU and in 1967 settled for 5550×10^{12} BTU. These data are reasonably consistent with the estimates of Vogely (1966) and those of the National Power Survey (FPC, 1964) and RFF (1963). However, its estimate in 1962 of a demand of $31{,}086 \times 10^{12}$ BTU (4.5×10^{12} Kw-hr.) in 2000 for electrical generation from nuclear sources[1] and the same amount from non-nuclear fuel seems extra-ordinarily high. If one projects electrical demand on the basis of the increase in per capita utilization in the 1955 - 65 period, then, assuming a population of 335×10^6 in 2000, the total demand will be only $26{,}000 \times 10^{12}$ BTU. This estimate is consistent with the RFF total (Table 26) of $37{,}010 \times 10^{12}$ BTU. To meet the AEC figure in 2000, one would have to multiply the per capita per year average increase during 1955 - 65, by a factor of 2-1/2. Such a major increase is conceivable only if there is a radical change in technology which makes electrical energy drastically more competitive, or other considerations supervene which militate in favor of its substitution.

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* The AEC data, published in Kw-hr., was converted to BTU at a heat rate projected for 1980 by Vogely and Morrison (1966).

[1] This was increased to $33{,}317 \times 10^{12}$ BTU in 1967.

Nuclear power may qualify on the former count as high-gain converters and breeders are developed, thus pushing unit costs down. The 1962 AEC report did not visualize full-scale breeders being built before 1980. In view of the current controversy within the AEC regarding which of the advanced reactors to stress, the technical difficulties with the Fermi-reactor, and the lateness of the present date, a more likely time-table seems to be 1980 - 90 for high-gain converters and 1990 - 2000 for initial operational use of breeders. An increased national consciousness with regard to atmospheric pollution qualifies as an "other consideration" and could cause a trend toward increased substitution of electrical energy for direct fossil energy, say, for space heating. Additionally, the development of an electric auto with suitable characteristics could make the AEC projection for 2000 more reasonable. In either eventuality the cause of pollution reduction would be served only if nuclear heat were substituted for fossil heat.

The implications for atmospheric pollution of the projections of electrical demand appear to be that (1) electrical energy will increase its share of the total market from about 20% to about 30% in the next 35 years (Table 25), (2) slightly more than half of the energy was supplied by coal in 1965; in 2000 it will drop to one-third, but the tonnage used will be about the same as that used in 1980 (3) while oil will not supply more than 1.2% of the total energy demand in this sector, one must take into account its geographical distribution. For example, New York and New Jersey combust about 30% of the 98 million barrels of residual fuel oil used by gas and electric power plants in the United States[1]. This concentration has led to an acute SO_2 problem in these two states.

Dr. Glenn Seaborg of the AEC has predicted (1966) that by 2000 all new power plants will be nuclear. If that should be the case, and obsolescent fossil fueled plants are replaced largely by reactors, two conclusions are evident: (1) the atmospheric pollution from fossil fueled electrical power plants will be self-liquidating eventually and (2) emissions from fission products must be examined closely for their own unique atmospheric pollutants.

From the above remarks and the data in Table 24, 25, and 26, it is clear that the principal users of coal are, and will continue to be, the electrical utilities and industry in that order; that after 1980 transportation and industry will be the prime users of petroleum products; and the principal users of gas are expected to continue to be industry on the one hand and the household and commercial sector on the other. As was indicated earlier, any decision with respect to abatement emphasis or priority, should, of course, take into account not only principal sources of pollutants within a sector but also their relative toxicity.

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[1] Petroleum Facts and Figures, API, 1965.

VI.C. Kr-85 and Atmospheric Pollution

With regard to nuclear fuel, it is generally recognized that Kr^{85}, a gaseous fission product with a 10.6 year half-life which emits both energetic beta and gamma rays, must be given special consideration. All other fission product gases have much shorter half-lives and so do not pose a serious health problem.

Monitors of radioactive pollutants of the atmosphere have reported (Ramey, 1966; Johnson, 1966) steady increases in the concentration of krypton-85, which cannot be accounted for by bomb tests alone but which must result from processing of irradiated nuclear fuels. Since the amount of energy generated by nuclear fission is increasing rapidly, there is concern over the possibility that dangerous atmospheric concentrations of persistent gaseous radioactive contaminants, produced by fission, will accumulate. It will be demonstrated below that krypton-85, the isotope with the greatest potential for long-term atmospheric contamination is not likely to be a very serious health hazard since means are available to prevent its escape into the air. However, it is also demonstrated that such escape should be prevented because it will be generated in sufficient quantity to constitute a hazard if unrestrained.

Table 27 shows that the yield of krypton-85 in fission depends upon both the isotope fissioned and the energy of the neutrons causing fission. While the total yield of kryptons varies widely, the distribution of isotopes remains quite constant; with Kr-85 accounting for 5.5 - 8.3 per cent of the total yield of kryptons.

Table 28 compares, on the basis of some recent estimates made by spokesmen for the USAEC, the growth of the nuclear power industry in this country and in the world, up to the year 2000.

While there is reasonably good agreement among various authorities concerning the general rate of increase in electrical power to be generated by nuclear sources, there is much conjecture about the advent of various alternative processes for the generation of such power. For example, at present, U-235 fission accounts for the great bulk of the nuclear power and that isotope is destined to play a dominant role in the immediate future. However, plutonium isotopes are expected to become increasingly important as time goes on, since U-238 must be the source material for "breeding" this fissionable compound if the major potential of the uranium resources is to be realized. Likewise U-233, which is bred from Th-232, will play an increasingly greater role. Plutonium breeds most efficiently in fast reactors which are expected to replace the thermal reactors currently in vogue. It should be noted in passing that the whole fission-reactor

Table 27

Krypton Yields in Fission*

krypton isotope	half-life years	Yields (%) from Fission by				
		thermal neutrons			fission spectrum neutrons	
		U-233	U-235	Pu-239	Th-232	U-238
Kr-83	stable	1.17	0.544	0.29	1.99	0.4
Kr-84	stable	1.95	1.00	0.47	3.65	0.85
Kr-85	10.6	0.58	0.293	0.127	0.87	0.153
Kr-86	stable	3.27	2.02	0.76	6.0	1.38

* Handbook of Nuclear Research and Technology, pp.163-169.

Table 28

Nuclear Power Generation Rates

Year	Electrical Megawatts	
	United States	Worldwide(3)
1970		100,000
1980	100,000(1)	735,000
1990		1,907,000
2000	500,000(2)	4,250,000

(1) James T. Ramey at American Nuclear Society Meeting in Pittsburgh, November 4, 1966.

(2) Wilfred E. Johnson at Atomic Industrial Forum Meeting in Pittsburgh, November 3, 1966.

(3) Glenn T. Seaborg at the British Nuclear Energy Society, October 24, 1966.

industry could become obsolete should the development of a controlled and sustained fusion reaction become a reality. Such obsolescence would stem from the fact that (a) complete "burning" of the deuterium fuel would produce about 14×10^{10} BTU/lb[1] while fission yields about 10^{10} BTU/lb, (b) the world-wide energy resources in deuterium are virtually inexhaustible (0.02% D in the hydrogen of water), (c) it has been postulated that the cost of energy from this source would be less than 1% of that from coal and (d) the reaction products are inert gases.

The prediction of exact quantities of Kr-85 as a function of time is necessarily imprecise because of the uncertainty as to nuclear fuel and neutron energy causing fission. It is, of course, possible to consider all possible, or reasonable, variations and construct an envelope within which the real answer must lie. However, such an exercise would be extremely tedious and not very enlightening.

Therefore, to gain perspective, an examination is made from the point of view of maximum permissible concentration (MPC). That is not to imply that anything like the maximum permissible concentration is anticipated or recommended, but only that it be used as a vantage-point from which to observe the problem.

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[1] The reactions are:

$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{T} + \mathrm{p} + 4\ \mathrm{Mev}$$
$$\mathrm{D} + \mathrm{D} \rightarrow \mathrm{He}^3 + \mathrm{n} + 3.25\ \mathrm{Mev}$$
$$\mathrm{D} + \mathrm{T} \rightarrow \mathrm{He}^4 + \mathrm{n} + 17.6\ \mathrm{Mev}$$
$$\mathrm{D} + \mathrm{He}^3 \rightarrow \mathrm{He}^4 + \mathrm{p} + 18.3\ \mathrm{Mev}$$

Energy/D = 7 Mev = 14.6×10^{10} BTU/lb D.

The International Committee on Radiation Protection (June, 1960) has set a value of 3×10^{-6} microcuries/cc of air as the MPC for continuous occupational exposure to Kr-85. For exposure of populations, the recommended level is only 1% as large; i.e. 3×10^{-8} microcuries/cc.

The mass of the atmosphere is 5.2×10^{21} grams, which corresponds to about 1.12×10^{44} molecules. If Kr-85 were uniformly distributed throughout the atmosphere at the MPC for populations, the number of atoms of Kr-85 per molecule of air would be about 1.93×10^{-14}. Table 29 shows the fission power rates which would represent an equilibrium condition for that concentration; i.e. if all the Kr-85 being generated were released into the atmosphere and decayed there at such a rate that its concentration remained stationary[1]. Comparing the MPC-equilibrium-powers of Table 29

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[1] An illustrative calculation using U-235 fission by thermal neutrons. The production rate, atoms of Kr-85/day is equal to the world-wide atmospheric decav rate, dN/dt

$dN/dt = (C_{Kr} M_{air})(\ln 2/\tau) = 3.87 \times 10^{26}$ atoms of Kr-85/day

where C_{Kr} = ratio of Kr-85 atoms in the air to air molecules.

M_{air} = number of molecules of air in the entire atmosphere

τ = half-life of Kr-85 (days).

The grams of U-235 fissioned per day, U_f, in order to maintain atmospheric equilibrium of Kr-85 is:

$U_f = (dN/dt)(1/F)(W/A) = 515 \times 10^5$ gms of U-235/day

where F = fractional yield from thermal fission of U-235

W = atomic weight of U-235

A = Avogadro's number

but 1 gm of any material (neglecting small differences in atomic weight) fissioned/day = 1 Mw (thermal) and assuming a thermal to electrical energy conversion efficiency of 32%, then the electrical power level P_{kr-85} that will maintain the world-wide atmospheric concentration of Kr-85 at the maximum permissible concentration, is:

$$P_{Kr-85} = 16.4 \times 10^6 \text{ Mwe.}$$

Table 29

Fission Power Rates for Atmospheric Equilibrium of Kr-85 Concentrations at the MPC for Populations

Fissioning Isotope	Neutron Energy	Electrical Megawatts
U-233	thermal	8,300,000
U-235	thermal	16,400,000
Pu-239	thermal	37,900,000
Th-232	fission spectrum	5,540,000
U-238	fission spectrum	31,500,000

with the projected powers for the year 2000 from Table 28, it is clear that the escape of Kr-85 into the atmosphere will eventually create an intolerable condition.

It is relatively easy to deal with this problem. Krypton is relatively easily separated from the other fission products and adsorbed on charcoal. The Kr-85 can, if necessary or desirable, be separated from the stable kryptons in an isotope separation plant (Isotopes and Radiation Tech. Vol. 3; Steinberg, 1964) and used, either as a source of power for light and for batteries or in other ways; or it can be destroyed by transmutation[1] through neutron absorption (Steinberg, 1964). Alternatively, krypton can be stored in either the adsorbed state or free of carbon as a gas.

The amount of Kr-85 corresponding to the MPC for populations is only 2.16×10^{30} atoms. This corresponds to 80,400 cubic meters at atmospheric pressure, which could be contained in a cube 142 feet on a side, or 804 cubic meters at 100 atmospheres pressure, which could be contained in a cube 30.5 feet on a side.

At room temperature and a pressure of 76 cm, activated carbon can hold more than 16 cc of krypton per cc of carbon, per atmosphere of krypton partial pressure. This fact may be useful in reducing either the pressure at which Kr-85 is stored or the size of the container in which it is stored. At lowered temperatures, the capacity of activated carbon for krypton is materially increased. If adsorbed at one atmosphere and 20°C., the entire volume of carbon on which 2.16×10^{30} atoms of krypton would be adsorbed could be contained in a cube which is 15.5 meters on each side.

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[1] Kr-85$(n,\gamma) \rightarrow$ Kr-86(stable).

VI.D. Combustion of Fossil Fuels and the Emission of Natural Radioactivity

While one associates radioactive emissions with nuclear reactors, fossil fuels contain natural radioactivity which concentrate by combustion. Although the concentrations are small, the enormous volumes of these fuels oxidized and the long half-lives of these nuclei may combine to produce a significant concentration in the atmosphere. This problem is assessed below for the city of Chicago.

Coal contains of the order of 1.1 ppm and 2.0 ppm of U-238 and Th-232 respectively; these decay to Ra-226 (τ = 1620y) and Ra-228 (τ = 6.7y) both of which have melting points of 960°C. A 1000 MWe coal burning plant will consume 2.3×10^6 tons/yr. of semi-bituminous coal (Eisenbud, 1964). Assuming 9% ash and 97-1/2% fly-ash collection, then 1200 tons of ash/yr. will be emitted containing 10.8 mCi of Ra-228 and 17.2 mCi of Ra-226 (Terrill, 1967) having a combined equivalence of 10^4 Ci of Kr-85 (Eisenbud, 1964).

Taking a median value for particulate production from coal in Chicago in 1965 (Table 20) and assuming similar fly-ash collection efficiency as above, then the equivalence of 4.0×10^5 Ci of Kr-85 will be vented to the atmosphere. The emission from oil and gas is negligible by comparison. The MPC for Kr-85 is 3×10^{-6} μCi/cc (ICRP, Health Physics, 1960). Using the value of 2×10^{-6} μCi/cc, the dilution factor for 1965, 1980 and 2000 was calculated. This factor is compared with the dilution factor required for Chicago based on SO_2 production (Table 22) and on MPC of 0.1 ppm.

Table 30

Dilution Factors Required for Fossil Fuels

	Equivalent Kr-85 Produced Ci/yr x 10^5	Air Dilution Factor/yr	
		Kr-85 Equivalence $M^3 \times 10^2$	SO_2 $M^3 \times 10^{12}$
1965	4.0	0.13	16.2
1980	5.2	0.17	20.1
2000	6.9	0.22	26.7

It is obvious that the dilution factors required for SO_2 are two orders of magnitude greater than those required to dilute natural radioactivity from fossil fuels.

It is concluded that while the health hazard from fission generated Kr-85 and naturally occurring radium isotopes cannot be ignored, the threat can be readily circumvented by technological means that are well-known.

VII. Benefits and Costs of Air Pollution Control

VII.A. Alternate Methods of SO_2 Pollution Abatement or Control From Coal: Their Economic and/or Social Implications

It is well recognized that control of pollutants from fossil fuel can be accomplished by four basic methods:

A. removal of the pollutants after combustion

B. removal during combustion

C. removal before combustion i.e. fuel modification

D. substitution by another fuel that contains less of the pollutant in question.

A detailed economic and technical evaluation of the alternatives for control of each of the major pollutants originating in fossil and nuclear fuels is beyond the purview of this report. However, in the following discussion, the SO_2 problem is treated in some detail; the concept and method is illustrative of the approach that is required in evaluating alternate methods of control for other pollutants.

In order to give some focus to this section, reference is made to the data in Tables 5, 14 and 15 for the ratios of SO_2 production from coal and oil in 1965, 1980 and 2000. These ratios suggest that coal produced about five times as much SO_2 in 1965 as did the petroleum products and that this ratio will not alter drastically in the foreseeable future provided the basic assumptions remain in force. Consequently, this section summarizes the various rationales for dealing with the SO_2 problem from coal, estimates the benefit/cost ratio associated with the solvent extraction process (SRC) and discusses its interpretation.

The specific measures pertaining to sulfur that can be identified according to the classification above are:

A. Removal of SO_2 from product gases by means of:

1. The Reinluft Process in which SO_2 is adsorbed on activated charcoal and, eventually, is converted to the final separated product, H_2SO_4.
2. The Alkalized Alumina Process in which the SO_2 is adsorbed on hot alkalized alumina followed by regeneration of the adsorber as a result of removal of SO_2 and conversion to elemental sulfur by a reducing agent.
3. The Catalytic Oxidation Process in which the formation of H_2SO_4, the final product, is preceded by the oxidation of SO_2 to SO_3.
4. The Coal-fired Fuel Cell in which H_2S is removed from waste gases after reduction of the coal to CO and H_2 but independently of power generation.

B. Immobilization of sulfur by combustion in the presence of dolomite (calcium and magnesium carbonate).

C. Fuel Modification.

1. Gasification. The Office of Coal Research of the Department of Interior is sponsoring research on the conversion of coal to methane; the latter would have sulfur concentrations no higher than natural gas i.e. < 50 grains/10^5 BTU (this corresponds to 0.09% sulfur coal). The gasification processes are:

    a. The CO_2 Acceptor Process of the Consolidation Coal Co.

    b. The Molten Salt Gasification Process of the M. W. Kellogg Co.

    c. The Hydrogasification Process of the Institute of Gas Technology.

    d. The Two Stage, Superpressure Entrained Gasifier of Bituminous Coal Research, Inc.

2. Extraction by

    a. Washing with water.

    b. Solvent extraction.

    c. Various magnetic and electrostatic methods.

D. Substitution. High sulfur coal might be replaced by:

    a. Low sulfur ($<$ 1%) coal.

    b. Natural gas.

    c. Low sulfur residual oil.

    d. Nuclear power for the generation of electricity.

Perusal of the above classification suggests that all the methods of SO_2 abatement involve either continued use of high sulfur coal accompanied by the application of new technological processes, substitution of high sulfur coal by coal that is naturally low in sulfur, or substitution by a different energy source.

VII.A.1. Continued Use of High Sulfur Coal

All of the technological processes i.e. those that start with high sulfur coal, have been subjected to detailed, continuing analyses (S. Katell, 1966; H. Perry and J. A. DeCarlo, 1966; Office of Coal Research reports on coal gasification by the M. W. Kellogg Co., Institute of Gas Technology, Consolidation Coal Co. and Bituminous Coal Research, Inc.; also OCR report on Gulf Oil Corp. process for producing solvent refined coal). All differ from each other with respect to the time required to bring the process to fruition, the development costs and the estimated cost for the treatment of coal on a production basis. None have any substantial social consequences other than benefits derived from a reduction in exposure to pollutants.

The time differentials, however, can be important in making comparative benefit/cost comparisons because of their impact on the discounted value of expenditures and benefits; in all of the processes referred to above, the time differences are not of sufficient magnitude to significantly alter the computed ratio.

This conclusion is based on the assumption that any one process will require 3 to 6 years for full development; if its practicality cannot be demonstrated in that length of time, the chances are excellent it will be discarded.

The processes under development of prime interest are the Reinluft, Alkalized Alumina and Catalytic Oxidation methods for the treatment of stack gases, the four coal gasification techniques for the production of methane and the coal energized fuel cell. The latter is based on coal gasification but the products are H_2 and CO. Coal cleaning by physical methods such as washing and electrolytic or electrostatic separation of pyrites are so inefficient that they are not regarded as potentially effective methods for sulfur removal.

The development costs required to bring any of the above processes to the point of commercial practicality are in the $5 - 10 million range. While a factor of two is not insignificant in the million dollar range, in the evaluation of the total costs accruing over an extended period as a result of routine treatment of the fuel, such development costs are trivial. This fact is brought out in the benefit/cost ratio developed below for solvent refined coal (SRC).

Since the social consequences connected with the employment of gasification or stack gas treatment relate to the benefits from damage reduction, the principal quantifyable variable is the operational cost per unit energy. These appear in Table 31. While there is a substantial difference between the cost for treating stack gases and costs for gasification, the expectation is that the gap will be considerably reduced by technological improvements in gasification by 1975 when it is expected to be ready for commercial use. However, it should be emphasized that pollution from coal consists of more than SO_2, that gasification will reduce the production of a number of combustion products including NO_x, and that this latter advantage has a significant monetary value which cannot be quantified at present.

All that can be said at this time is that gasification of coal is believed to be somewhat more expensive than stack gas treatment as a means of reducing pollutant emissions; as more information on costs is developed, a detailed "trade-off" or benefit/cost analysis should be performed taking full credit for benefits flowing from reductions in all relevant pollutants.

The coal-fired fuel cell is a special case. In this device, which is being developed by Westinghouse, coal is converted to CO and H_2; in the process of generating electrical power by direct energy conversion, oxidation occurs and CO and H_2 are converted to CO_2 and H_2O (Figure II). The reaction debris, in addition to CO_2 and H_2O, consists primarily of ash and H_2S; the latter is quantitatively trapped in the process stream. Such a system not only has inherent pollution advantages but it can result in

Table 31

Coal: Estimated Costs Associated With Effluent Treatment and Gasification

		Cents/10^6 BTU	
Effluent Treatment		Process Cost	Process Plus Fuel Cost
Reinluft	800 MW, 3% S	9.58[1]	34.0[2]
Alkalized Alumina	800 MW, 3% S	6.00[1]	30.4[2]
Catalytic Oxidation	800 MW, 3% S	6.84[1]	31.2[2]
Gasification			
CO_2 Acceptor	$1.50/ton lignite		40[3]
Molten Salt	$4.00/ton bituminous		48[3]
Hydrogasification	$4.00/ton bituminous		43-48[3]
Superpressure Entrained Gasifier	$4.00/ton bituminous		50[3]

[1] S. Katell, 1966.

[2] Based on an "as burned" price of 24.4¢/10^6 BTU (Steam-Electric Plant Factors/1965).

[3] Coal Gasification Approaches Pilot Plant Stage, Chemical Engineering News, April 18, 1966.

substantial cost reductions for electrical power. Present estimates are that it will average about 60% efficiency in contrast to steam-electric power which averages about 35%. A recent study indicated that a 1000 MW unit could produce electrical energy for $<$ 3 mills/KW-hr[1] in contrast to present rates of about 7 mills/KW-hr[2]. The former compares favorably with the present 4 mills/KW-hr[3] for light water cooled reactors in the 1000 MWe range and the projected cost of about 3 mills/KW-hr[3] for near breeders and breeders in the same power range.

The coal-fired fuel cell is, of course, limited to power generation. However, the process, as presently visualized, is so inherently "clean" and the projected power costs so cheap that the process could very well result in substantial social changes. For example, it could not only contribute to reduced atmospheric pollution but the relatively cheap electrical power[4] could take over a much larger fraction of such functions as home heating and cooking; it could reduce mass transportation costs and costs associated with operating an electric automobile.

[1] United Engineers and Constructors Inc., Review and Evaluation of Project Fuel Cell, Report to the Office of Coal Research, Dec. 2, 1966.

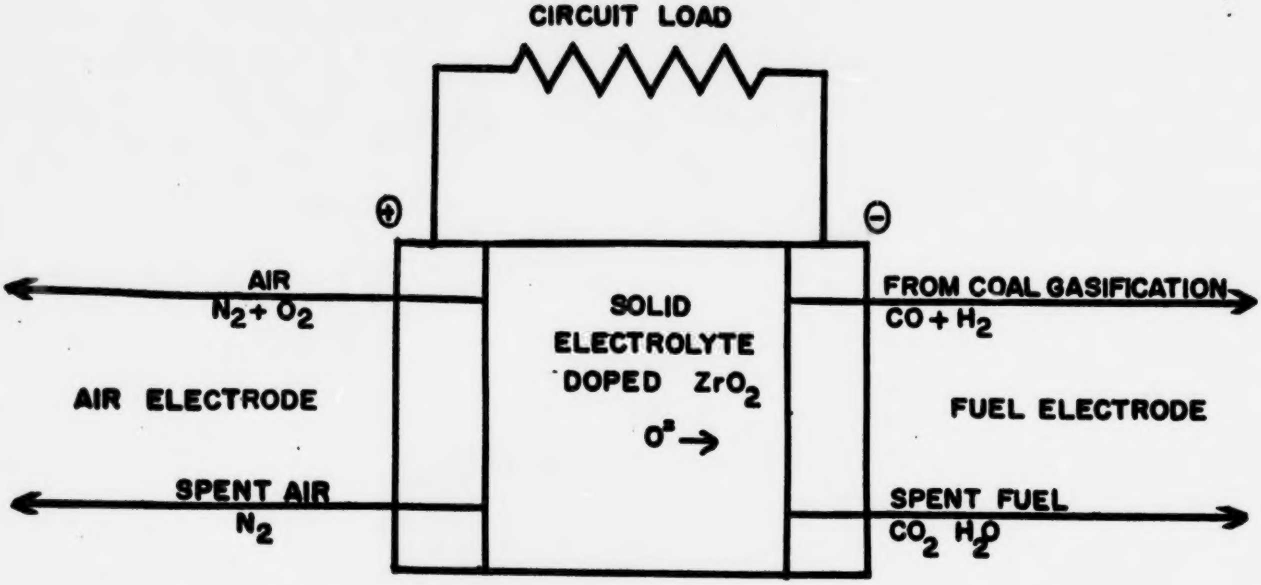
[2] National Power Survey, 1964, Part I, p.68.

[3] Seaborg, G. T. (1966), Figs. 8 and 13.

[4] Such a development could give added momentum to the trend toward an electrical economy and make the 1962 and 1966 projections of the AEC for the electrical demand in 2000 more believable.

FIG. II

SCHEMATIC OF THE COAL-FIRED FUEL CELL*


CIRCUIT LOAD
⊕
⊖
AIR
$N_2 + O_2$
AIR ELECTRODE
SPENT AIR
N_2
SOLID
ELECTROLYTE
DOPED ZrO_2
$O^= \rightarrow$
FROM COAL GASIFICATION
$CO + H_2$
FUEL ELECTRODE
SPENT FUEL
CO_2 H_2O

MATERIALS FOR THE AIR AND FUEL ELECTRODES ARE UNDER DEVELOPMENT. PRESENTLY FARORED ARE Sn DOPED InO FOR THE AIR ELECTRODE AND Co DOPED WITH Zr FOR THE FUEL ELECTRODE.

*REVIEW AND EVALUATION OF PROJECT FUEL CELL, UNITED ENGINEERS AND CONSTRUCTORS INC. REPORT TO OFFICE OF COAL RESEARCH. DEC.2,1966

Without carrying out a detailed analysis of the benefit/cost ratio, it is obvious that this device has a number of very attractive features; if a substantial fraction of the goals are achieved, it could have significant social and institutional effects as well as cost advantages.

The program on coal gasification and direct energy conversion from coal was initiated by the Office of Coal Research (OCR) principally to meet competition from other energy sources. The anti-pollution features are largely extra dividends. Irrespective of the motivation behind the program, the pollution abatement potential is so great, it is suggested that the Public Health Service consider taking a more active role, in cooperation with the OCR, in evaluating the various systems from the technological and social point of view as well as their future impact on the energy industry. Further, as evidence of its continuing interest and cooperation, it would be appropriate for the Public Health Service to support those projects it believes are most likely to make a substantial contribution to air pollution abatement.

From a consideration of the above factors, it was concluded that in the case of continued use of high sulfur coal, in order to compare costs of sulfur removal from the natural fuel or its combustion products by means of one method with the costs associated with another method for accomplishing the same end (identical benefits), direct comparison on the basis of costs per unit energy is justified without resorting to benefit/cost analysis.

On the other hand, where there are appreciable differences in benefits and also in costs, as is likely when there are social disruptions, time differentials or hidden as well as direct costs, then the benefit/cost ratio can be a useful analytical adjunct. Each of the four substitutions in category "D" above has significant social consequences; the methodology for a B/C evaluation of this group is outlined in sections VII.A.2. through VII.A.5. The substitution of solvent refined coal for untreated coal entails no significant social disruptions but because of R and D costs as well as the incremental costs of the final product, which can be compared with the benefit derived (SO_2 avoidance), a B/C analysis can be informative. This option is analyzed in detail in VII.C.

VII.A.2. Substitution by Low Sulfur Coal ($< 1\%$ S)

According to estimates of the Bureau of Mines and the Geological Survey, reserves of coal as of 1965 are about 1576×10^9 short tons; approximately 2/3 are low sulfur coals. Most of these low sulfur reserves are in the western part of the United States, remote from the industrialized centers. Their distribution by states and sulfur content is shown in Table 32 (Perry, Sept. 1966).

Considering the major coal categories, approximately 98% of the lignite reserves are situated in North Dakota and Montana; their sulfur content is $< 0.7\%$. Approximately 96% of the subbituminous coal is in the western states and Alaska; this coal is generally low in sulfur but it may run as high as 2%. Two-thirds of the bituminous deposits are east of the Mississippi but almost 80% have a sulfur content > 1% (383.8×10^9 tons vs. 95.3×10^9 tons).

Appalachia contains nearly 31% of the bituminous reserves of the United States (724.6×10^9 tons) most of it being concentrated in West Virginia; 46% of the coal in West Virginia is of the low sulfur variety (47.5×10^9 tons).

In the past, the demand for coal from the electric utilities has generally been met on the basis of the price F.O.B. the plant and heat value without regard to sulfur content. Should the latter become a major consideration, new sources of supply of low sulfur coal would have to be established. In this event, two major consequences would supervene: (1) the price paid by the utility per unit heat value would rise because of increased transportation costs (increased distances from mines to utilities) and greater competition for the low sulfur coal and (2) there would be a social impact on the lives of the miners.

The average length of haul of coal to utilities in the United States in 1963 was 296 miles and the average cost of the transportation was $3.11/ton (1.05 ¢/ton-mile); the 1965 data

Table 32

Estimated Remaining Coal Reserves of the United States By Rank, Sulfur Content and State on Jan. 1, 1965.

(Million short tons)

Coal rank and State	Sulfur content									Total a/
	0.7% or less	0.8 - 1.0%	1.1 - 1.5%	1.6 - 2.0%	2.1 - 2.5%	2.6 - 3.0%	3.1 - 3.5%	3.6 - 4.0%	Over 4.0%	
Bituminous coal:										
Alabama	889.2	1,189.3	5,421.7	5,182.8	458.8	417.4	---------	---------	18.6	13,577.8
Alaska	20,287.4	1,100.0	---------	---------	---------	---------	---------	---------	---------	21,387.4
Arkansas	---------	---------	1,128.4	293.1	154.0	---------	40.3	---------	---------	1,615.8
Colorado	25,178.3	37,237.2	---------	---------	---------	---------	---------	---------	---------	62,415.5
Georgia	---------	76.0	---------	---------	---------	---------	---------	---------	---------	76.0
Illinois	---------	573.7	4,942.4	2,615.1	809.6	16,583.8	33,650.4	57,652.2	19,062.0	135,889.2
Indiana	197.5	173.0	3,645.2	4,248.8	3,563.4	4,110.5	10,872.8	5,103.9	2,944.0	34,861.1
Iowa b/	---------	---------	---------	---------	---------	---------	117.1	---------	6,405.4	6,522.5
Kansas	---------	---------	519.9	519.7	1,038.7	2,070.6	4,148.0	18,287.3	4,153.8	30,738.0
Kentucky:										
West	---------	---------	1,119.6	162.0	336.3	3,793.6	12,759.3	13,643.3	5,081.3	36,895.4
East	13,639.9	8,491.9	2,288.8	1,658.8	1,158.3	2,154.4	24.7	---------	---------	29,416.8
Maryland	---------	---------	---------	124.6	191.8	208.2	378.6	56.4	220.4	1,180.0
Michigan	---------	---------	---------	---------	---------	---------	---------	205.0	---------	205.0
Missouri	---------	---------	---------	---------	---------	---------	6,456.7	20,669.2	51,634.1	78,760.0
Montana	51.2	218.2	205.0	397.2	400.0	175.0	40.0	27.0	591.0	2,104.6
New Mexico	5,212.0	5,474.0	---------	---------	---------	---------	---------	---------	---------	10,686.0
North Carolina	---------	---------	---------	---------	---------	110.0	---------	---------	---------	110.0
Ohio	---------	611.0	369.0	2,110.2	2,750.4	7,810.5	9,785.3	10,148.2	8,439.4	42,024.0
Oklahoma	250.6	772.2	825.0	368.1	---------	---------	577.2	19.1	490.6	3,302.8
Oregon	---------	14.0	---------	---------	---------	---------	---------	---------	---------	14.0
Pennsylvania	44.0	1,156.6	7,626.4	12,424.9	19,689.5	9,995.6	5,287.6	1,150.5	580.6	57,951.5
Tennessee	3.3	160.9	715.9	258.7	178.2	190.5	219.7	43.8	68.5	1,839.5
Texas	---------	---------	---------	---------	7,978.0	---------	---------	---------	---------	7,978.0
Utah	8,551.4	13,584.0	---------	1,524.9	---------	---------	---------	---------	3,997.7	27,658.0
Virginia	1,981.5	6,077.5	1,637.1	---------	123.9	---------	---------	---------	---------	9,820.0
Washington b/	898.9	672.1	---------	---------	---------	---------	---------	---------	---------	1,571.0
West Virginia	20,761.0	26,710.6	21,819.7	13,290.6	8,496.1	2,491.8	3,147.4	5,949.2	---------	102,666.4
Wyoming	6,222.2	6,596.6	---------	---------	---------	---------	---------	---------	1.1	12,819.9
Other States c/	---------	616.0	---------	---------	---------	---------	---------	---------	---------	616.0
Total	104,168.4	111,502.6	52,260.1	45,179.5	47,307.0	50,111.9	87,505.1	122,937.1	103,688.5	724,680.2
Percent of total	14.4	15.4	7.2	6.2	6.5	6.9	12.1	17.0	14.3	100.0
Subbituminous coal:										
Alaska	71,115.6	---------	---------	---------	---------	---------	---------	---------	---------	71,115.6
Colorado	13,320.8	4,908.7	---------	---------	---------	---------	---------	---------	---------	18,229.5
Montana	94,084.4	36,728.0	0.5	1,303.7	---------	---------	---------	---------	---------	132,116.6
New Mexico	38,735.0	12,000.0	---------	---------	---------	---------	---------	---------	---------	50,735.0
Oregon	87.0	87.0	---------	---------	---------	---------	---------	---------	---------	174.0
Utah	---------	---------	150.0	---------	---------	---------	---------	---------	---------	150.0
Washington b/	3,693.8	500.0	---------	---------	---------	---------	---------	---------	---------	4,193.8
Wyoming	35,379.7	72,515.6	---------	---------	---------	---------	---------	---------	8.6	107,903.9
Other States d/	---------	4,047.0	---------	---------	---------	---------	---------	---------	---------	4,047.0
Total	256,616.3	130,586.3	150.5	1,303.7	---------	---------	---------	---------	8.6	388,665.4
Percent of total	66.0	33.6	0.1	0.3	---------	---------	---------	---------	(e)	100.0
Lignite:										
Alabama	---------	---------	20.0	---------	---------	---------	---------	---------	---------	20.0
Arkansas	280.0	70.0	---------	---------	---------	---------	---------	---------	---------	350.0
Montana	60,214.5	24,141.6	2,660.9	---------	---------	464.7	---------	---------	---------	87,481.7
North Dakota	284,129.1	34,987.3	31,581.6	---------	---------	---------	---------	---------	---------	350,698.0
South Dakota	---------	2,031.0	---------	---------	---------	---------	---------	---------	---------	2,031.0
Texas	---------	---------	6,902.0	---------	---------	---------	---------	---------	---------	6,902.0
Washington	---------	116.6	---------	---------	---------	---------	---------	---------	---------	116.6
Other States f/	---------	42.0	---------	---------	---------	---------	---------	---------	---------	42.0
Total	344,623.6	61,388.5	41,164.5	---------	---------	464.7	---------	---------	---------	447,641.3
Percent of total	77.0	13.7	9.2	---------	---------	0.1	---------	---------	---------	100.0
Anthracite:										
Alaska	2,101.0	---------	---------	---------	---------	---------	---------	---------	---------	2,101.0
Arkansas	---------	---------	---------	145.5	286.3	---------	---------	---------	---------	431.8
Colorado	---------	90.0	---------	---------	---------	---------	---------	---------	---------	90.0
New Mexico	---------	6.0	---------	---------	---------	---------	---------	---------	---------	6.0
Pennsylvania	12,211.0	---------	---------	---------	---------	---------	---------	---------	---------	12,211.0
Virginia	335.0	---------	---------	---------	---------	---------	---------	---------	---------	335.0
Washington	5.0	---------	---------	---------	---------	---------	---------	---------	---------	5.0
Total	14,652.0	96.0	---------	145.5	286.3	---------	---------	---------	---------	15,179.8
Percent of total	96.5	0.6	---------	0.9	2.0	---------	---------	---------	---------	100.0
Grand total	720,060.3	303,573.4	93,575.1	46,628.7	47,593.3	50,576.6	87,505.1	122,937.1	103,697.1	1,576,186.7
Percent of total	45.7	19.3	5.9	3.0	3.0	3.2	5.5	7.8	6.6	100.0

a/ United States Geological Survey Bulletin 1136, with adjustments for production and losses in mining through 1964.
b/ New estimates from report in preparation or in press.
c/ Arizona, California, Idaho, Nebraska, Nevada.
d/ Arizona, California, Idaho.
e/ Less than 0.1 percent.
f/ California, Idaho, Louisiana, Nevada.

is probably not very different[1]. The average F.O.B. plant price for coal was 23.9¢/10^6 BTU and the "as burned" price was 24.4¢. Natural gas averaged 26.7¢/10^6 BTU while oil was considerably more, 33.2¢/10^6 BTU. Assuming that prices have held constant, coal transportation costs could, in theory, only tolerate an increase of 9% before feeling intense pressure from gas competition. As a practical matter, this differential is probably not significant since no cost allowance has been made for fly-ash control, ash-handling, or ash sales for dumping or brick manufacture. The principal restraining factor in the coal vis-a-vis natural gas relationship is the stated policy of the Federal Power Commission which favors combustion of coal rather than natural gas in the utility industry.

Any benefit/cost analysis based on the substitution of low sulfur for high sulfur coal would require an evaluation of altered transportation costs on a plant-by-plant basis and an estimate of the alteration in the mine-mouth price, if any, resulting from increased competition for the more limited sources.

In theory, a coal miner can work anywhere so that changes in source of supply should not result in unemployment. In practice, it can be expected that a fraction of the miners would relocate

[1] The "whopper-hoppers" which are only now coming into use may reduce the cost per ton-mile slightly.

and a fraction would not. Historical data supports the thesis that a substantial fraction of the miners who do not relocate will remain unemployed because of lack of skills or unavailability of opportunities requiring unskilled labor; past experience has shown that they will continue to live on welfare payments for extended periods. Others will obtain training and find non-mining employment. Therefore, any plan that contemplates a realistic evaluation of the costs of substitution of low sulfur for high sulfur coal should analyze (a) relocation (b) unemployment (c) retraining and welfare costs. The sum of these costs appropriately discounted would be added to the discounted increased transportation costs for the low sulfur coal.

The benefit/cost derived from such a substitution can then be expressed in units of SO_2 avoided per unit cost as discussed above.

VII.A.3. Substitution by Natural Gas

It is unrealistic to consider substitution of all high sulfur coal by natural gas both from the point of view of resource depletion and from the point of view of social impact. Rather, one should direct this type of action toward those urban areas that have demonstrated SO_2 burdens which exceed the presently accepted limit of 0.1 ppm a substantial fraction of the time.

Natural gas is needed to replace high sulfur coal in quantity during the next 6 to 8 years only. After that time has elapsed, manufactured gas from coal can be expected to start phasing in. Also, natural gas from Venezuela is available today but, in view of the saturated condition of world shipyards, it would take about five years to design, build and launch "reefers" to transport liquified natural gas. Consequently, foreign natural gas should be thought of as a competitor to coal (via the manufactured gas route) as well as domestic natural gas.

Substantial capital investments, such as those required by the fuel industry, are made only if there is to be a use requirement over a sufficiently long time to permit a pay-out. With a short-term pay-out, the rate of required return becomes prohibitive. Therefore, if the replacement of high-sulfur coal by domestic gas in the immediate future is to be considered realistically, the following factors have to be considered:

(1) identification of those urban areas with unacceptably high SO_2 levels.
(2) estimation of the fraction of high-sulfur coal used in those areas that must be replaced by natural gas to achieve the desired reduction in atmospheric SO_2.
(3) computation of (a) the capital investment in additional pipeline facilities to serve these needs

and those that will develop over the next six to eight years, and (b) the cost of converting the boilers from coal or oil to natural gas.

(4) computation of the price differential between natural gas and the high sulfur coal over the next six to eight year period.

(5) estimation of the cost of social disruption in the form of unemployment, retraining costs, welfare costs, etc. over the 6 - 8 year period.

(6) beginning in 1975, reversal of the social dislocation in mining communities will probably be initiated; the cost penalty created by this reversal, as applied to other industries, should be examined.

The Federal Power Commission has jurisdiction where the interstate transportation, importation or questions of end use of natural gas are involved. Although its attitude could change, in the past it has been intransigent where it considered natural gas would be put to an "inferior" use. Consequently, the FPC would have to be convinced that (1) the replacement of coal by gas would indeed improve the health of the population and (2) that this objective cannot be achieved in any other practical way.

VII.A.4. Substitution by Low Sulfur Residual Oil

This possibility can be implemented in the near future by first selectively importing residual oils that are low in sulfur and secondly removing the sulfur during the process of refining whether the latter is carried out in domestic or local refineries.

Bechtel (June 1964) in its widely quoted study concluded that low sulfur residual oils can be produced in new domestic refineries at 40 to 65 cents additional per bbl. and 48 to 78 cents per bbl. in existing refineries.

In this case, one can make the following assumptions:

(1) starting in 1967, high sulfur coal in highly polluted urban areas is replaced on a graduated basis; the process is completed in 1975.

(2) the cost of desulfurizing remains static over the 8 year period.

(3) the social disruptions begin in 1967 and correspond to those previously discussed.

(4) in 1975 gasification of coal is initiated and gradually takes over various fractions of the utility market; this could vary from the annual incremental requirements to displacement of low sulfur residual oil.

As in previous calculations, the net benefit and cost are expressed as a ratio of units of SO_2 removed per dollar of cost.

VII.A.5. Replacement by Nuclear Power

This is not a likely possibility. First, reactors can only substitute for coal in the electrical utility industry which accounted for only about 50% of the total coal use in 1965. A second important factor to be considered is that the presently projected rate of construction of thermal (non-breeding or converting) neutron reactors between 1967 and 2000 will substantially reduce domestic U_3O_8 reserves which can be purchased at less than $10/lb. Since mineral energy resources are an inverse function of unit price, the domestic reserves are considerably expanded if the price is increased. The AEC (1967) has recently published its revised estimates of U_3O_8 requirements to 1980 and their relationship to reserves.

Table 33[1]

U_3O_8 Requirements to 1980 and Their Relation to Resources

	U.S.	Free World Excluding U.S.
Requirements x 10^3 tons U_3O_8	170	240
Requirements As A % of Resource Category*		
$10/lb Reasonably assured	85	50
$15/lb Reasonably assured	49	23

[1] AEC, 1967 Supplement to 1962 report on Civilian Nuclear Power, p.7.

* The requirements are based on demand through 1980 and not on the life of the reactor.

The data suggests that although supplies are certainly adequate through 1980 at the lesser price, one can expect a rising trend in U_3O_8 costs. Indeed, the 1965 price of \$4-5/lb has already risen to \$6-7/lb.

Seaborg (1966) has correlated the known and estimated free-world reserves of U_3O_8 with the projected proliferation of free-world reactors. Assuming a 30 year life-time for current light-water and advanced gas-cooled reactors, he estimated the time spans for which free-world reserves, known and estimated, are adequate.

U_3O_8 Cost/lb	MWe x 10^3	Estimated date on which MWe will be committed
\$10 or less	300	1980
\$15 or less	550	1985
\$30 or less	1000	1990

U-235 based thermal reactors are twice as sensitive to changes in fuel charges as are breeders (and high-gain converters). Thus an increase from \$8/lb to \$15/lb for U_3O_8 would increase the cost of generating electrical power by 0.50 and $<$ 0.25 mills/Kw-h for non-breeders and breeders respectively[1]. When one combines this information with the inherently cheaper generating costs of breeders (4 mills/Kw-h for non-breeders vs. 3.5 mills/Kw-h for breeders at 12-1/2% fixed charges and 80% load factor in the 1000 MWe size[1]), the relatively limited supplies of U_3O_8, and the projected rate of nuclear reactor construction, one has a compelling case for developing high-gain converters and breeders

[1] Seaborg (1966).

with all deliberate speed. The best informed opinion is that this cannot be accomplished before 1990 - 2000.

The above discussion suggests that since the free-world reserves of uranium that cost up to four times present prices are already committed if present projections of nuclear power requirements hold up, any additional substitution of nuclear power for high sulfur coal between the present and the end of the century would be extremely expensive. However, in order to gain a better appreciation of the economic and social import of nuclear power to society, it is suggested that a benefit/cost analysis based upon coal vis-a-vis nuclear be made and that it consist of two phases:

1. the 1975 - 2000 time period which would compare coal and coal derivatives with light water and gas cooled reactors.
2. the 2000 time period and beyond when uranium resources would be less critical because breeders would be available and would be the basis of comparison with high sulfur coal.

In performing both phases of the analysis, nuclear reactors should be credited with a value assigned for pollution abatement or, conversely, coal-fired furnaces should be penalized for pollution damage. In making power generation cost comparisons, it is not now the custom to take such a factor into consideration.

VII.B. Some Estimates of Health Damages

Numerous and almost uniformly unsuccessful attempts have been made to assess the damage sustained on an annual basis due to exposure to atmospheric pollutants. (A broadly interpreted list of references is appended). The indices of pollution damage fall into two broad categories (1) direct damages such as maintenance costs of structures and their appurtenances, deterioration of products such as crops, damage to people and animals, accidents attributable to pollution etc. and (2) indirect effects which usually require a subjective evaluation: reduced real estate values, protracted vacations, choice of alternate modes of transport etc. Most of the effort has been directed at category (1) with very limited success. One of the more successful attempts has been that of Ridker (1966) to evaluate the major direct costs but, as he points out, "the specification of the cost factors to be attributed to air pollution . . . are not known; and where some estimates have been made they are in considerable dispute." Indeed he has emphasized that more is to be gained from projecting future pollution levels and thus an index of rising or falling pollution costs than is to be gained from accurate data on the costs themselves. While one always feels more comfortable about using costs that can be substantiated, particularly where major policy decisions are involved, most purposes can be served by using relative rather than absolute damage data based on guesstimates.

With this caveat in mind, Ridker (July 1966) has estimated the cost of home maintenance resulting from pollution to be $1.09 billion out of $6.6 billion and $0.1 billion* out of $2 billion to be the cost of losses from diseases attributable to pollution. The fractionation of the latter figure was accomplished by taking into account such factors as differences in urban and rural mortality rates, under-reporting from rural areas, differences in smoking habits etc. The best that one can say is that pollution contributes to human disease in an amount totalling less than $2 billion, possibly of the order $0.1 billion*. When it comes to ascribing portions of the $0.1 billion to individual pollutants, the degree of uncertainty is compounded to the point where such an estimate is valueless.

While Ridker has reported estimated direct damage data [illegible] a wide variety of objects as well as people, his data for human population damage is examined for illustrative purposes. His calculations take into account not only population growth but projected changes in the GNP. His results[1] are:

1963	1970		1980	
	low	high	low	high
x 10^6	x 10^6		x 10^6	
$100.	$159.	$167.	$255.	$300.

---

* There appears to be some confusion as to the amount ascribable to pollution. Ridker on page 2 refers to $0.4 billion and on page 11 to $0.1 billion.

[1] Ridker, [illegible] G., July 1966, Table 7.

Presumably the low and high figures represent not only uncertainties in growth rates and GNP's but also the proliferation of anti-pollution measures. The latter in particular are demonstrating not only exponential growth but, equally important, are being more stringently enforced. When one couples these factors with increasing fuel substitution and the rapidly advancing technology for removing or avoiding the emission of pollutants from fuels[1], some question is raised as to whether the rate of increase in the 1970 - 80 period may not be too high. However, taking the above data at face value, then on the basis of the population in 1963 and the projections for 1970 and 1980:

	Population x 10^6	Av. Damage to Humans x 10^6	Damage Cost /Person
1963	189	100	$0.53
1970	207	163	$0.79
1980	251	278	$1.11

The above cost per person in 1963 represents an insignificant fraction of the widely quoted - and widely disputed - figure of $60. per person for total pollution costs in 1958[2] The latter would represent a total out-lay for pollution costs of $10,440 million (in 1958) which is very close to the total 1963 direct costs arrived at by Ridker: $9,697 to $11,247 million.

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[1] Desulfurization of residual oil and coal by a variety of techniques, gasification of coal, the coal energized fuel cell, MHD etc.

[2] For a review of the basis for this figure see Kneese, A. V., December 1966.

If one estimates the fraction of the above "Damage Cost/Person" ascribable to SO_2, say 0.50, the cost per person is indeed trivial. However, certain factors should be kept in mind. The above costs represent identifiable organic disease and they do not include psychic costs of illness or costs of death and losses due to lost productivity. One additional but very important point is adduced: the cost of human damages per person on a statistical basis may be small to the point of being trivial but the effect is usually concentrated in the chronically ill, the very young and very old. Since these represent, at any moment, but a small fraction of the total, the cost per person may indeed be significant. Statistical Abstracts of the United States-1966, lists 6.6 persons per 1000 of all ages as receiving home care in 1959 (Table 111, p. 83). Assuming that 25% of these have overt or incipient pulmonary impairment, that only one in 25 is incapacitated as a result of air pollution and that this ratio does not change with time, then, based on Ridker's estimates, the annual cost/capita for pollution connected illness is:

	$/cap
1963	$12.83
1970	19.09
1980	26.85

While this study is not intended as a survey of the pollution damage literature, one other report, that of Michelson and Tourin (1966) is worthy of mention because of the excellent methodology which is illustrative of the quality of information that can be gained by the comparative method. In this study, Uniontown, Pa., and Steubenville, Ohio were selected because the two towns are similar climatically, socially and economically; they differed only in that Steubenville had a significantly higher atmospheric pollution level than Uniontown. The criteria of pollution costs, were such expenses as hair and facial care, laundry and inside and outside maintenance of homes. Data indicated that the gross difference expended for damage control was $84. per person. While such trivia as hair and facial care are readily quantifiable, the progression to medical cost from this data must be purely stochastic. It is to be hoped that a similar methodology will be applied to a study of medical costs de novo.

VII.C. A Benefit/Cost Analysis of Solvent Refined Coal

Jimeson (1966) has reported economic comparisons between the use of solvent refined coal (SRC), natural coal and oil and concluded that

(1) there is a national average cost penalty of 14¢/10^6 BTU if SRC is substituted for natural coal in existing power plants.

(2) there is a national average cost advantage of 8¢/10^6 BTU if SRC is substituted for oil in existing power plants.

(3) if power plants are specifically designed for the use of SRC, in 1980, a credit of 14¢/10^6 BTU for reduced operational costs would make SRC competitive with untreated coal.

A benefit/cost analysis has been made of substituting SRC for untreated coal in the electrical utility industry using the following assumptions

(1) SRC will reduce the sulfur content to 1% by weight irrespective of the original concentration.

(2) the national average sulfur content of coal used in power plants is 2.5% (Rohrman, 1965).

(3) the SRC process will not be ready for large scale commercial application until 1975.

(4) the rate of replacement of untreated coal by SRC will increase by 10%/yr so that by 1985 and, thereafter, all coal plants will burn only SRC.

(5) all but about 5% of coal used in power plants substantially exceeds the 1% level attainable by SRC.

(6) it costs 14¢/10^6 BTU to treat coal by the solvent recovery method.

(7) contrary to the projections in the Jimeson report, no credit is taken for reduced maintenance in new SRC plants; neither is credit taken for the newly developing market in the brick industry for fly-ash. Although these credits will partially off-set each other, note should be taken of the fact that cost projections of newly developing technologies usually err on the optimistic side and that at least two technological difficulties remain to be "ironed out." These are, first, the melting point,

220° C, which requires either preheating to about 300° C to permit combustion as a fluid or alteration of the chemical structure to raise the melting point substantially and, second, the minimum sulfur concentration attainable in SRC, as mentioned in (1) above, is about 1%.

(8) 1967 is the initial year from which all costs are calculated and is the base to which the stream of costs and benefits are normalized or discounted.

With these limitations and assumptions in mind, a calculation was made of the added costs that would be incurred between 1975 and 2000; these were compared with the "benefit" to be derived in order to establish a benefit/cost ratio. The benefit is assessed in terms of SO_2 not emitted to the atmosphere.

The basic bench marks in this calculation are the known and projected coal requirements in the U.S. electrical utility industry as given in Table 24:

Year	Coal x 10^{12} BTU
1965	6,043
1980	11,487 (mean)
2000	10,950 (RFF data)

Between 1965 - 80, the rate of increase, r, on a continuous flow basis is given by

$$r = (1/t)(\ln(E/E_o)) \qquad (2)$$

in which: t is the elapsed time in years

E is the energy demand from coal at time, t i.e. 1980

E_o is the initial energy demand at t_o, 1965.

Once the rate, r, for the period 1965 - 80 has been determined, energy demand from coal for any single year between 1965 and 1980 can be ascertained by means of (2). Also the total (integrated) energy obtained from coal, ΣE, can be calculated for any fraction of this time period from the relationship

$$\sum_{t_o}^{t_1} E = E_o \int_{t_o}^{t_1} e^{rt}\,dt = (E_o/r)\,[e^{rt}]_{t_o}^{t_1} \qquad (3)$$

For the 1965 - 80 time span, r was calculated to be 4.277×10^{-2}/yr; for the 1980 - 2000 period it was assumed to be zero, since the difference between the estimated coal demand in 1980 and 2000 by the utility industry is not regarded to be significant. Thus the first column in Table 34 gives energy demand from coal for the years specified while the "Total" column is the integrated energy demand over the period indicated.

The second alternative assumes that SRC will be ready for commercial use in 1975 and could be introduced into the electrical utility industry at an accelerated rate of 10% per year i.e. 10% of the 1975 total coal utilization in 1975, 20% in 1976 etc.

Then the energy contributed by SRC, E^{SRC}, in any year, t, is:

$$E_t^{SRC} = kte^{rt}E_o \tag{4}$$

where k is a constant and represents the acceleration of the replacement rate of untreated coal by SRC. Then the integrated energy obtained from coal between t_o and t_1 is expressed by:

$$\sum_{t_o}^{t_1} E^{SRC} = kE_o \int_{t_o}^{t_1} te^{rt}dt = \frac{kE_o}{r^2} [e^{rt}(rt-1)]_{t_o}^{t_1} \tag{5}$$

Note that E_o is the rate of total energy demand from coal at t = o. The summed energy expenditures for the specified time periods that apply to the substitution of SRC for untreated coal appear in Table 34, under the heading "SRC." The coal energy not supplied by SRC, is, of course, obtained from untreated coal; these quantities appear under the heading "(Total minus SRC)."

VII.C.1. SRC Costs

The recent trend in coal prices indicates a steady decline (Steam Electric Plant Factors, 1965); the "as burned" recent historical costs are:

Year	¢/10^6 BTU
1960	26.0
1961	25.8
1962	25.6
1963	25.0
1964	24.6
1965	24.4

Projecting this trend:

1975	21.2
1980	19.6
1985	18.0
2000	18.0

Table 34

Projected Energy Demand From Unrefined and Solvent Refined Coal by the Electric Utility Industry: 1967 - 2000

		Integrated Energy Demand For the Period Indicated x 10^{15}			
Year	Energy Demand From Coal x 10^{15}	Period	Total	SRC*	(Total minus SRC)
1967	6.58	1967 - 74	63.22	0	63.22
1975	9.25	1975 - 79	51.88	12.52	39.36
1980	11.49	1980 - 84	63.52	50.02	13.50
1985	11.49	1985 - 99	172.3	172.3	0
2000	11.49				

* Substituted at an accelerating rate of 10%/yr - see text.

Since the price of coal is determined by a multiplicity of competing as well as independent factors, not the least of which is inflationary trends, and cannot go to zero, it can reasonably be assumed that the price of coal will be stable between 1985 and 2000.

The extra costs associated with the introduction of SRC at the rate specified above until the year 2000 were calculated using appropriate average values for the periods specified. Thus, for example, on the basis of the demand data in Table 34 and the "as burned" rates above, the cost of untreated coal in 1975 - 79 without substitution of SRC would be:

$$(20.4\text{x}10^{-2})(51.88)10^{15}10^{-6} = \$10.58\text{x}10^{9}$$

and for the case where SRC is partially substituted, the latter would cost

$$(20.4+14)10^{-2}(12.52)10^{15}10^{-6} = \$4.307\text{x}10^{9}$$

The difference in total cost between substitution and non-substitution under the assumptions specified for the 1975 - 1999 time span appears in Table 35.

Although there is a considerable difference of opinion as to the appropriate discount rate, most economists agree it should be in the 6 - 12% range. A rate of 6% was elected; no allowance was made for inflationary trends which would reduce this rate. 6% corresponds to a continuous discount stream of 5.82%. The discount period is then from mid-time frame to 1967, for example

Table 35

Comparison of Projected Costs*

Untreated and Solvent Refined Coal

1975 - 2000

	Av. Cost/10^6 BTU		Cost of Coal x 10^9			Extra Costs x 10^9
	Coal	SRC	All Untreated Coal	SRC	Untreated Coal	
1975 - 79	20.4¢	34.4¢	$10.58	$4.307	$8.029	$1.756
1960 - 84	18.8	32.8	11.94	16.41	2.538	7.008
1985 - 99	18.0	32.0	31.01	55.14	0	24.13
Total			53.53	75.86	10.567	32.894

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* Non-discounted.

1977.5 to 1967. The discount value was then calculated from equation (2) which takes the form

$$P_o = P_t/(e^{rt}) \qquad (6)$$

where P_o = principal in 1967 and P_t = principal at any t.

Period	rt	e^{rt}	P = \$ x 10^9	P_o = \$ x 10^9
1975-79	.0582(10.5)	1.84	1.756	0.954
1980-84	.0582(15.5)	2.46	7.008	2.85
1985-99	.0582(25.5)	4.41	24.13	5.47
			Total	9.27 x 10^9

The preliminary research pertaining to SRC has been completed and the project is now (1967) at the stage where it is ready for a pilot plant facility. Assuming that Congress votes the funds, \$7 million, for the project in this session, it is estimated that 6 years will be required to design, build and operate it long enough to obtain meaningful data. The funds thus appropriated might reasonably be spent at following rate:

Year	Expenditure x 10^6	Expenditure x 10^6 Discounted to '67*
1967	\$ 0.5	\$ 0.50
1968	3.5	3.30
1969	2.0	1.78
1970	0.50	0.420
1971	0.25	0.198
1972	0.25	0.186
	Total	\$ 6.384 x 10^6

* Continuous discount rate of 5.82% or 6%/yr.

The total extra expenditures discounted to 1967 are then:

extra costs for SRC	$\$9.27 \times 10^9$
Development (pilot plant)	6.38×10^6
Total Costs	$\$9.28 \times 10^9$

It is apparent that the development costs are trivial compared to the discounted extra costs for SRC.

VII.C.2. SRC Benefits

Sufficient information is not available to permit benefits to be equated with the dollar value of injury prevented by the use of SRC, but benefits can be expressed in units of SO_2 prevented from reaching the combustion chamber. Since SO_2 is not a universal medium of exchange, the benefit/cost ratio derived from this approach has limited value in that it can be compared only with those processes that involve SO_2 removal and does not permit a trade-off between heterogeneous systems which would involve dissimilar substances - say, SO_2 removal vs. prevention of hydrocarbon emission or vaccine development. Were the monetary value of the benefits known, the converse would, of course, be true.

The quantities of SRC burned from 1967 to 1999 (Table 34) amounted to 234.84×10^{15} BTU or the equivalent of $((234.84 \times 10^{15})/26 \times 10^6)(.015) = 13.5 \times 10^7$ tons of SO_2.

This calculation assumes a national average of 2.5% sulfur in the coal used by electric utilities (Rohrman, 1966) and that the present SRC process cannot reduce the sulfur content of coal below 1%.

Since SO_2 removed is equivalent to a benefit function which has a monetary value, it can be discounted just as monetary costs are[1]. Discounted to 1967 at the 6% level previously used:

	ΣE^{SRC} x 10^{15} BTU	Equivalent[a] SO_2 - tons x 10^6	t	e^{rt}	SO_2 Discounted to 1967 tons x 10^6
1975-79	12.52	7.22	10.5	1.84	3.92
1980-84	50.02	28.9	15.5	2.46	11.7
1985-99	172.3	99.4	25.5	4.41	22.5
				Total	38.12 x 10^6

[a] 26 x 10^6 BTU/ton; SO_2 reduced from 2.5% to 1%.

The benefit to cost ratio then is:

$$(38.12 \times 10^6)/(9.28 \times 10^9) = 4.11 \times 10^{-3} \text{ tons of } SO_2 \text{ removed per extra dollar expended.}$$

The above computation suffers, in addition to a lack of flexibility, to two additional major short-comings: (1) it gives no indication of the acceptability of the processed system i.e. no figure-of-merit appears in the calculations to indicate the damage value of solvent refined coal containing 1% sulfur and, more important, (2) there is no indication that the damage avoided (the benefit) by sulfur removal is a function of the pre-existing atmospheric concentration. Consideration of the latter fact suggests that the SO_2 monetary "benefit" has a regional or urban value which can vary quite widely - depending on whether Chicago or Medicine Bow is involved. Stated differently, each unit of atmospheric concentration of SO_2 avoided has a value which depends on the pre-existing atmospheric concentration of SO_2.

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[1] The damage value per unit of SO_2 is a function of the atmospheric concentration of that pollutant. Hence an error is introduced if the initial atmospheric levels in the time frames above differ significantly.

It is generally accepted that a procedure or system is justified only if the benefit/cost, both expressed in dollars, exceeds unity. For the above stated reasons, no direct judgment is possible with regard to the justification of substituting SRC under the condition specified, except it is clear that the actual benefit associated with the sulfur dioxide prevented from reaching the atmosphere, expressed in \$/ton of SO_2 must exceed the reciprocal of the B/C ratio as calculated in order to make the process economically desirable.

Hence: $\text{Benefit/ton } SO_2 \geqq \$243$

Ridker (1966) has estimated the losses incurred from all pollutants for 1963, 1970 and 1980. For illustrative purposes, his data, using the average of the high and low estimates which include a 6% annual credit of the residential property losses, have been interpolated to yield a total damage estimate for 1967. This value is $\$6814 \times 10^6$. The total production of SO_2 in 1967, also interpolated from the data in Table 16, was estimated to be 23.9 x 10^6 tons. Based on the minimum benefit/ton of \$243 required to make the SRC process attractive, the total benefit from SO_2 removal in 1967 would have to be \$5808 x 10^6, a value that is 85% of Ridker's total pollution damage estimate.

VII.C.3. Conclusion - SRC

In view of the multiplicity of pollutants and their wide variation in damage effects both qualitatively and quantitatively, it is concluded, on the basis of Ridker's data, that the SRC process is not an attractive one i.e. the pollution damage resulting from exposure to SO_2 is probably considerably less than 85% of the total and probably is in the 25 - 50% range. Since the cost of pollution damages is in an area in which guesses are permissible, this author is of the opinion that if the Ridker data is too low by a factor of two to four, as is possible, then the SRC process might begin to look desirable from an economic point of view.

VIII. Fuel Policies and Their Relation to Pollution

The preceding projections of future energy demand and the sources that are expected to supply that demand have a high degree of uncertainty connected with them not only because of changing trends in the population growth rate but also because such factors as changing political alliances, wars, discovery of major new sources of fossil fuels, technological breakthroughs in MHD and fusion etc. singly or in combination could have great impact. One consideration, air pollution - in retrospect it might be described as a "sleeper" - is already causing serious repercussions in the energy market and there is much more to come. The rising tide of popular opinion against not only air pollution but pollution of all kinds coincides with another development of major import to the energy market: it is now generally accepted that nuclear power has "turned the corner" economically and is prepared to compete for new electrical facilities on a non-subsidized basis. The following discussion pertains to government policies, explicit and implicit, as they pertain to energy sources and attempts to draw some conclusions as to their effects, past and future, on energy sources.

"Policy" in the energy field is a conglomeration of policies by the Federal, state and local governments. These policies were arrived at by improvisation as the need arose and generally are aimed at (a) maintaining an "orderly" i.e. healthy economic fuel market and (b) assuring the country of a continuing supply of fuels in peace and war. Therefore, it is clear that it has been the national policy for many decades to foster the development of a healthy domestic fossil fuel industry and, as a concomitant, to encourage exploration for new sources. More recently, since World War II, it has been national policy to develop civilian nuclear power to the point where it can compete on a non-subsidized basis with fossil fuels in the market-place.

During the '60's, as atmospheric pollution increased, often to intolerable levels, there has been increasing pressure from all levels of American life to find ways to reduce it. This pressure culminated in the Clean Air Act of 1963 and its amendments of 1965 and 1966. Many new and significant amendments have already been proposed for the 90th session of Congress in 1967. In order to gain an understanding of contemporary government policies and to project the direction in which we as a nation are moving with respect to energy sources and associated pollutants, it is instructive to review the historical background of some of these policies.

The two principal sources of SO_2 in the atmosphere are coal and oil; which one contributes more depends on the geographic area. In Los Angeles, oil is the only significant source since coal is not burned at all. In Chicago in 1965, the ratio of coal-SO_2 to oil-SO_2 was 13:1 (Table 20) which Rohrman (June 1966) et al. have pointed out that a 400 mile swath stretching from lower Pennsylvania to parts of Vermont and New Hampshire accounted for the consumption of one-third of the total U.S. annual use of residual fuel oil - 19.7×10^6 bbls out of 359×10^6 in 1964. The sulfur content, they report, approximated an average of 2.5% by weight yielding 1.64×10^6 tons of SO_2 in that year. The same geographic area produced 1.77×10^6 tons of SO_2 from coal (Rohrman et al. 1965) in 1963. Most of the residual oil burned on the east coast is imported from Latin American countries, especially Venezuela, while only 13% originated in the U.S. in 1964. This condition arises from a combination of economic, political and historical factors.

VIII.A. Residual Oil

As a result of the discovery of large domestic oil reserves in the late 20's, a federal import duty of $0.21/barrel for crude and residual oil and in excess of $1.00/barrel for refined products was imposed in 1932. It was felt that a healthy domestic industry was an essential adjunct to national security and that such a condition could not exist in the face of cheap foreign oil. Since the import duties did not have sufficient inhibitory effect, the total import was restricted shortly thereafter to 4-1/2% of 1932 domestic production. The threat of foreign competition in the U.S. quickly faded; by 1938 exports had reached a peak of 16% (530,000 bbl/day) of domestic crude production. Net exports declined steadily after 1938 and by 1948 the U.S. had become a net importer - a condition that exists today. By 1955 imports had reached such a level that Congress empowered the President to limit the import of any commodity if he was of the opinion that existing import quantities threatened national security presumably by causing disruption of or dimunition below acceptable levels of a domestic industry. In 1959, President Eisenhower determined that such a condition existed and initiated the present mandatory oil import program.

The oil import control program which applies to all petroleum products is administered through the Office of Oil Import in the Department of Interior. It carries out its function by issuing licenses to qualified companies on the basis of geographical location, facilities and prior business history. The residual oil import program applies only to PAD I (Petroleum Administration for Defense); the latter consists essentially of the New England, Middle Atlantic and South Atlantic states down to and including Florida. Total import quotas are determined by the estimated difference between domestic supply and demand.

The total demand for residual oils has fluctuated between 460 - 470,000 bbl/yr. In 1965, it seemed to be appreciably higher: over 500,000 bbl (Table 36). However, the fraction supplied from non-U.S. sources has steadily increased as a result of decreased domestic production:

Table 36

Domestic Demand and Import of Residual Oil

	Domestic Demand *	Import **	
	bbls x 10^3	bbls x 10^3	%
1960	465,355	163,520	35
1961	461,370	173,010	37
1962	461,398	194,910	42
1963	462,422	209,300	45
1964	471,557	233,600	49
1965	506,433	280,320	55

* Excludes vessel bunkering; bunkers for 1965 estimated.
** Corrected for bonded imports used for bunkering and export.

U.S. residual oil will average about 1% sulfur by weight. Imports will range from 1.55% from Colombia to 4.5% from Mexico; the average sulfur content of imports was 2.54% (Rohrman et al, 1966).

As mentioned above, the original concept behind the oil import quotas was that the U.S. oil industry needed protection from cheap foreign competition although national defense was also considered as a motivating factor. With the drying up of the U.S. sources of residual oil, this raison d'etre for regulation of residual imports no longer has the compelling validity it once had. However, with the passage of time, something new has been added: it has become clear that, since enactment of the law in 1954, the threat from oil imports is as much to the health and well-being of the population as it is economic.

Two alternatives for making residual oil more acceptable on public health grounds are well recognized and considerable thought and effort is being given to their implementation. These are removal of SO_x compounds from flue gases and removal of sulfur from the residual oil before it is burned. A third alternative, the substitution of liquified natural gas from foreign sources for residual oil, remains to be explored[1]. In view of the relatively limited supplies of domestic natural gas (see the section on Resource Adequacy) the latter proposal would appear to be worthy of more detailed investigation.

The replacement of imported residual oil originating in friendly Western countries without adequate provision for the economic repercussions within the economies of those countries could seriously affect our relations with them. On the other hand, it may be possible to meet our anti-pollution requirements without disrupting relations with our allies by substituting, for example, Venezuelan natural gas for Venezuelan residual oil. Preliminary information suggests that there are large deposits of gas available and that the Venezuelans have a limited market for this fossil fuel. It is suggested that all aspects of this substitution - economic, technical and political - are worthy of more detailed study[2]. The above facts notwithstanding, the

[1] I am indebted to Dr. F. A. Rohrman, USPHS-Cincinnati, for this suggestion.

[2] See Memo from L. M. Sharpe to R. Longaker, USPHS, March 6, 1967.

Marathon Oil Company of Palmyra, Ohio, and the Phillips Petroleum Corp. have recently been authorized by the Federal Power Commission to export liquified natural gas from the North Cook Inlet and Kenai gasfields in Alaska to Japan at an average rate of 620 million cubic ft per year for 15 years. The export of natural gas to Mexico and Canada is an established practice within our national fuel policy but the net flow in recent years has been very much in our favor. Thus in 1964:

	Canada		Mexico	
	To	From	To	From
Natural Gas Sales - \$ x 10^6	3.4	94	5.9	103

In contrast to the sales to Canada and Mexico, the above sales to Japan represent a net loss to our national fuels resources but a gain of about $18 million per year in foreign exchange. On the surface, natural gas policy within the FPC would appear to be inconsistent: it has denied permission to some utilities to expand their use of natural gas, principally on the grounds of preventing "inferior" usage, while authorizing the export of this fuel.

It is recommended that all aspects of our national natural gas policies, taking into account such aspects as economics, foreign policy, potential technological developments, resource adequacy, pollution, etc. should be examined with a view to developing a coherent, consistent and coordinated program.

VIII.B. Regulation of Fuel Production

As described above, the Office of Oil Import has been the sole arbiter with respect to the import of finished and unfinished petroleum products including residual oils since 1959. Domestic crude oil and natural gas production is regulated in virtually all states (the older producers, Illinois, Indiana, Kentucky, Ohio, Pennsylvania, Tennessee, Virginia and West Virginia excepted) by appointive bodies; regulation is based on what is considered to be sound conservation practice and demand but no effort is made to control the nature or quality of the end products. Almost all states severely limit gas venting or flaring. This was originally a conservation measure; more recently it is considered to be an anti-pollution measure as well.

In order to maintain an orderly market in anthracite, the State of Pennsylvania controls its production through a committee made up of state officials, United Mine Worker and producer representatives.

Generally the state regulatory bodies can influence prices only in that they control production rates. Thus they have power, indirectly, to permit the producers to remain competitive.

VIII.C. Policies Pertaining to Fuel Utilization

As a result of an awakened consciousness on the part of the public, health organizations at federal, state and local levels are beginning to shape fuel selection policy within the total energy demand and, inevitably, production policies. This influence is being exerted by the federal government directly as a result of the Clean Air Act of 1963 (42 USC 1857) in which it is charged with, among other things, responsibility for (a) aiding in the development of cleaner automotive fuels and residual (high sulfur) oils and (b) initiating abatement proceedings under specified conditions where unacceptable interstate air pollution situations exist. This law was followed on May 26, 1966 by Executive Order 11282 which specifically directed that (a) budgets for the construction of new federal facilities include funds for air pollution control and (b) estimates be prepared for modifying existing buildings so as to minimize the danger to health from air pollution. As a direct result of the above executive order it was proposed by the Public Health Service (Federal Register Vol. 31, No. 226, dated Nov. 22, 1966) to limit the emission of sulfur oxides (calculated as SO_2) from all federal facilities in the New York Standard Consolidated Area to 0.35 lbs/10^6 BTU; in the Chicago S.C.A. and the Philadelphia Standard Metropolitan Area the proposed limit is 0.65 lbs/10^6 BTU[1].

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[1] This proposed regulation took effect March 23, 1967. See the Federal Register, Vol. 32, page 4415.

The immediate effect of the above legislation and executive order is to give the affected federal facilities the following options: (a) limit their use of residual oils to those containing no more than 0.33% sulfur by weight in New York and 0.62% sulfur in Chicago and Philadelphia (b) switch to more expensive petroleum distillates which contain acceptable concentrations of sulfur (c) substitute natural gas for oil or (d) heat by electricity. Option (a) is a possibility in the immediate future but as the demand for this product grows as a result of anti-pollution pressures options (b) or (c) may have to be employed. Option (d) is feasible in new buildings only but it will make a net positive contribution to minimizing air pollution only if the source of the electrical power is nuclear and not fossil fuel energy.

At present it is technically feasible to reduce the sulfur content of residual oil in domestic refineries but there is a penalty of about \$0.50/bbl of residual oil for processing California crude so that the residue contains no more than 0.5% of sulfur by weight. The additional cost is then \$0.09/10^6 BTU. This and a number of other options for desulfurization of crude and residual oil in U.S. refineries were reported by the Bechtel Corporation (June 1964). A study sponsored by the American Petroleum Institute which is specifically directed at analyzing the costs of desulfurizing foreign residual oil in foreign (Central American) refineries is presently in progress at the same company.

At the local level, Los Angeles, Rules 62 and 62.1, ban the burning of any gaseous fuel containing more than 50 grains of sulfur per 100 ft^3 (calculated as H_2S at 60° F, 14.7 psi) or any liquid or solid containing more than 0.5% by weight of sulfur in the summer. Further coal and oil may not be burned, except under special circumstances in the winter. Since coal is not burned in Los Angeles, and natural gas rarely exceeds 50 grains of sulfur, the regulation effectively prohibits the burning of high-sulfur ($>$ 0.5% S) residual oil at any time. A recent attempt to replace the low sulfur oil burned by the utility industry in Los Angeles County in the summer with natural gas on a number of grounds, including reduced atmospheric pollution, was denied by the Federal Power Commission (see Opinion 500 dated July 26, 1966, pertaining to the TRANSCO case). More recently (February 1967), the County of Los Angeles has barred all future construction of fossil fueled electric utility plants or the modernization of old ones within the confines of the county limits; on the other hand, nuclear electric utilities are not barred. It remains to be seen whether this regulation will lead to increased construction of hydro, remote fossil fueled, or more proximate nuclear utilities. In any event, as of the present, pollution considerations have had greater impact on fuel selection and electric utility siting in Los Angeles County than in any area in the United States.

The New York metropolitan pollution situation has been highly publicized. A principal point of attack on the problem has been the coal and oil burning plants of the Consolidated Edison Corporation. In 1961, the city had worked out a plan for reducing the emission rate of SO_2 from these plants on the basis of a gradual reduction in the sulfur content of the oil from 2.3% to 1% by 1971. The Mayor of New York - the city burned 113.4×10^6 bbl. of residual oil in 1964 of which 98.4×10^6 bbl. (2.5% sulfur average) were imported - has expressed his concern and dissatisfaction with the rate of progress of the present Con Edison anti-pollution program and is pressing for more rapid action. As of the present time, the suppliers of fuel oil are canvassing world markets for low sulfur residual supplies. Domestic refiners do not have the capacity to desulfurize large quantities of foreign residual imports; any increased capacity would require substantial capital investments[1]. New York is in competition primarily with other east coast cities for these supplies, since, as mentioned previously, oil import of residual oils is limited to PAD I.

The net effect of these anti-pollution measures is as yet unclear. It could drive the price of higher grades (low sulfur) oil up thus raising the cost of electrical power or it might cause the Federal Power Commission to reconsider its position concerning Con Edison's current application to be permitted to bring in additional supplies of natural gas for combustion in New York City. (See reply brief of the Federal Power Commission staff dated 12/30/66 in the case of TRANSCO. Docket No. CP 65-181; also see below the discussion of the role of the FPC in creating pollution and fuel policy.)

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[1] Con Edison suppliers are reported to have been assured of substantial supplies of low sulfur residual oil in Nigeria.

It is obvious that those abatement processes which involve either fuel modification or fuel substitution have an effect on fuel utilization policies. Thus substitution of natural or manufactured gas for oil or up-grading of coal or oil as a result of pollution considerations would qualify as changes resulting from fuel policies. Only where the pollutants can be removed from the stack gases satisfactorily, as is the case with particulates, does abatement not impinge on fuel policy.

A number of other anti-pollution measures will undoubtedly affect the future selection of energy sources and can be classed as fuel policy. Under the Clean Air Act of 1963, the Federal government can initiate proceedings against interstate polluters at the request of responsible state officials or, if they fail to take action, on its own initiative. Eight such actions are now pending[1]. Further, the President has proposed to Congress

[1] Two were initiated by the Secretary of H.E.W. on his own initiative and six at the request of state officials.

the enactment of the "Air Quality Act of 1967" in which the Secretary of Health, Education and Welfare would have the authority to set emission standards for designated industries and to establish Regional Air Quality Commissions where an interstate pollution problem exists but where there is no adequate control program.

The effect of the above and future anti-pollution actions on fuel selection, modification and substitution as well as emission control will undoubtedly be considerable but the full impact cannot be clearly discerned at this time.

VIII.D. The Federal Power Commission and Fuel Policy

The Federal Power Commission has strongly influenced regional fuel policy in recent decisions. The role of the Federal Power Commission (FPC) has been an evolving one since its origin in 1920 as a hydro-power licensing agency for non-Federal projects. In 1935, under the Federal Power Act, it was given jurisdiction over the wholesale rates charged for interstate transmission of electric energy and the business affairs of the utilities concerned; the Natural Gas Act of 1938 gave the FPC control over its interstate transport of natural gas and the rate structure, provided the gas was for resale.

Pollution had not been a major issue in FPC proceedings until the Transcontinental Gas Pipeline Corp. (TRANSCO) requested authorization from the FPC to supply natural gas to the Consolidated Edison Corp.; the request was denied on various grounds including: (1) the TRANSCO proposal, if approved, would not significantly decrease air pollution and (2) that the combustion of additional gas, in contradistinction to other fossil fuels, was wasteful and represented an "inferior" use. TRANSCO appealed to the Supreme Court twice and in landmark decisions, 320 US 591 and 365 US 1, the Court reaffirmed a 1943 decision. In these decisions the court decided that (1) in order that sound conservation practice be employed, the end use of gas was a proper consideration and (2) air pollution was relevant to end use. Having had its power to regulate the combustion of natural gas based on end use clearly reaffirmed by the U.S. Supreme Court, the FPC has used this power to require a substantial reduction in an existing threat to public health before permitting the burning of additional quantities of natural gas for the generation of electricity (Opinion 500, FPC, dated July 26, 1966).

In view of the pollution considerations, the Department of Health, Education and Welfare has intervened in proceedings before the FPC in four cases. Three are concerned with applications to be permitted to burn additional quantities of gas and have been partially justified by the applicants on the basis of reduced pollution*. The fourth is the application of Consolidated Edison of New York to be permitted to install a pumped power station at Cornwall, New York. Testimony is being taken in the latter case as of the writing of this report.

In the Florida Gas Transmission Co. case, the examiner disregarded all testimony pertaining to pollution in reaching his decision since the applicant stated that the customer, Florida Power and Light, merely wished to alter the oil-gas mixture so as to eliminate visible plumes. The examiner, finding this reason trivial, and having been presented, in his opinion, no supporting substantive data by HEW or Florida Gas Transmission in re air pollution as it existed prior to application consideration, denied the request. The full Commission recently reversed this decision[1] but the question of pollution was not a major consideration.

The Gulf Pacific, Transwestern, El Paso case pertained to requests by these pipeline companies to be permitted to supply additional quantities of natural gas to southern California in the Los Angeles area. A number of options were presented but essentially El Paso and Transwestern proposed to supply additional gas on demand (TSP or Tailored Supply Program) while Gulf Pacific required a long term commitment without the "demand" feature. One variant proposed by all three competing companies was to supply additional gas in quantities such that the fuel oil market would have been virtually eliminated in Southern California. A major reason advanced by the Southern California Edison Corp. and the Los Angeles Department of Power and Water was that the combustion of additional quantities of natural gas rather than oil would result in a partial but substantial alleviation of the atmospheric pollution problem in Southern California.

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* 1. Gulf Pacific Pipeline Co., Transwestern Pipeline Co. and El Paso Natural Gas Co. See Opinion 500 of the FPC dated July 26, 1966.
2. Transcontinental Pipeline Co. (TRANSCO). See initial briefs and reply briefs of FPC and HEW; decision pending.
3. Florida Gas Transmission Co. See Examiner's Initial Decision dated July 7, 1966.

[1] Opinion No. 516, March 1, 1967.

On December 16, 1965, FPC Examiner A. A. Kurtz issued a decision in favor of Gulf Pacific for a number of reasons including the conclusion that granting of a license would reduce significantly the air pollution of Los Angeles County.

Following institution of proceedings before the full Commission, HEW was permitted to intervene as amicus curiae and presented its evidence on March 28-29, 1966, in favor of permitting the delivery of additional quantities of gas but took no position with respect to selection of one or more applicants.

In Opinion 500, dated July 26, 1966, the full Commission reversed Examiner Kurtz and held that (1) El Paso and Transwestern rather than Gulf Pacific should be certificated on the basis of TSP since a long term commitment to specified quantities of gas was not warranted in view of developments in nuclear power and long distance high voltage transmission from coal-fired plants as well as hydro power and (2) the pollution evidence was equivocal with respect to its nature, and its impact on health.

Opinion 500 of the FPC is most illuminating because it placed a group of individuals, trained in the legal profession, in the position of evaluating testimony from air pollution experts as to the deleterious effect of atmospheric pollutants in concentrations prevalent in southern California. In the opinion of the majority of the Commissioners, the medical evidence was inconclusive and they further observed that no one had yet defined satisfactory atmospheric standards for all the pollutants in question.

These proceedings have brought out as no other have, that expert opinion is not enough, and that there is a void of considerable dimensions in our knowledge of the relationship between chronic low-level exposure to atmospheric pollutants, the synergistic relationships between them and, therefore, the atmospheric criteria or standards that can logically be derived from that information.

As a result of the above proceedings, the FPC certificated Transwestern and El Paso to supply incremental gas until 1968 only and noted that the advent of nuclear power, the tie-in with the Bonneville Power Administration and the use of remote fossil fuel plants may combine to diminish the importance of fossil fuels and consequently the contribution to air pollution in the Los Angeles area by the utilities. It is interesting that the public health authorities of Los Angeles County have accomplished by edict what the Los Angeles Bureau of Power and Water in concert with H.E.W. was unable to - and more: in February 1967 the construction of all new electrical generators energized with fossil fuels was banned in Los Angeles County as an anti-pollution measure. Whether this will lead to the construction of remote fossil fuel, or proximate nuclear electricity generating stations remains to be seen. Present indications are that the availability of electrical networks and extra-high voltage transmission lines on the one hand, which make possible remote coal and residual oil fired utilities, and falling nuclear power costs, makes a mix of the two likely.

A third landmark case is currently in process before the FPC. It is concerned with the petition of the Transcontinental Pipeline Corp. (TRANSCO) to be permitted to supply Con Edison of New York City with an additional 20.075×10^9 ft^3 of natural gas annually. All of the additional gas would be used for the generation of electricity. TRANSCO, Con Edison and the City of New York filed briefs requesting certification while H.E.W.

recommended certification be conditional upon agreement by Con Edison to burn gas at selected generating stations when dictated by unfavorable atmospheric conditions.

The status of the case as of this date is that the FPC staff has filed initial and reply briefs as has H.E.W. As was the situation in the Southern California case, a major point at issue is not the need for more energy fuel but rather whether the use of natural gas as opposed to oil or coal will make a significant contribution to minimizing air pollution. And again, the FPC and HEW are cast in the role of adversaries with the FPC placing the burden of proof on the applicants and H.E.W. to demonstrate "public convenience and necessity" i.e. demonstrate a significant reduction in air pollution in order to justify an "inferior" use.

In attempting to protect the nation's natural gas supplies from inferior uses, the FPC staff has taken the position that it is unwilling to accept expert opinion on those aspects pertaining to pollution. To illustrate, it has attacked the recommended MPC for SO_2 of 0.1 ppm as being of doubtful validity[1]. There are literally scores of MPC's for air, food, water, drugs etc. and all represent the considered judgment of experts. No MPC is ever "frozen in concrete" but is subject to revision as new evidence accumulates. No one can guarantee that an MPC to which individuals are exposed will not be injurious because the occurrence of sequelae to exposures is statistical in nature. Even the same person may show different responses depending on his physical condition. The FPC staff characterized the evidence for the SO_2 MPC as "inconclusive" and, therefore, presumably unacceptable. On the other hand, its questioning of the SO_2 contribution that Con Edison makes to ground level concentrations is pertinent, as well as its observation that SO_2 levels are highest in the winter[1] while Con Edison proposes to burn most of the gas in the summer (only 19% of the total 20.075×10^{12} ft^3 would be consumed in the production of electricity during the five month heating season).

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[1] Initial Brief of the FPC Staff re TRANSCO, December 12, 1965, p.15.

The FPC staff noted the relationship between the high level of atmospheric pollution in the winter and the proposed low rate of gas combustion in that season by Con Edison[2] and cites this inverse relationship as a reason for denying the application. On the other hand, it states that the preferential use of gas in the winter should be for space heating. From the FPC briefs, the ostensible reason that so little gas is available for electrical generation in winter is precisely because it has been pre-empted for home and commercial building heating. In order for Con Edison to minimize its SO_2 contribution in the winter, it would appear to be necessary to bring in additional quantities of gas. It is not clear from the record whether the capacity of the transmission and/or storage system will permit this alternative. From the record, it would appear that Con Edison is supporting the FPC staff's position by preferentially supplying gas for heating purposes.

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[1] For data see FPC Staff Initial Brief re TRANSCO, December 12, 1966, p.26.

[2] Ibid. p.3.; also FPC Staff Reply Brief, December 30, 1966, pp. 3, 23.

The observation by the FPC that the combination of tall stacks and high efficiency of combustion combine to yield less pollution per unit of fuel by Con Edison is interesting but irrelevant since it is the atmospheric concentration and, therefore, the contribution per unit time that is important. On the other hand, H.E.W. did not present field data but theoretical calculations to support its contention that Con Edison was a major contributor to ground level concentrations. In this facet, both sides are drawing conclusions from assumptions whereas it should be possible to devise means of tracing SO_2 at ground level back to the originating utility smoke-stack. One possibility that may be worth exploring is IR spectroscopy[1].

It is not the purpose of this analysis and summary to refute or support point by point any of the positions in the Con Edison proceedings; that is a function of the parties concerned. However, after reviewing the evidence it appears that there may be a solution that can be implemented without compromising the basic position of either the FPC staff, H.E.W. or the applicants.

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[1] The Brookhaven National Laboratory is attempting to follow SO_2 dispersion using radioactive isotopes.

It is the prime responsibility of the FPC to ascertain that the proposed end use of natural gas is consistent with sound conservation of this national resource and, once that test is met, to permit its use at prices that are fair to both the seller and the buyer. Exceptions to established conservation practice can be made only where other compelling reasons, such as a contribution to public health, are extant. Such an exigency exists in the New York City area according to the Department of H.E.W., but the staff of the FPC is sufficiently unconvinced to oppose this exception.

It is difficult to disagree with the posture that all national resources should be used in a manner so as to maximize NET! public benefit whether considering health or consumer costs; additionally, any measure which meets the above test and spares that resource for the use of future generations should receive detailed and profound consideration.

There are two alternatives that will meet the test of public benefit and resource conservation. These are (1) the promise of evolving technology for converting coal to methane and for a coal-fired fuel cell and (2) the importation of liquified natural gas (LNG) from foreign countries such as Venezuela.

Four gasification processes have already been alluded to in Section VII and the expected costs for 10^6 BTU are indicated in Table 31. The CO_2 Acceptor and the Hydrogasification Processes are the most advanced and, if Congress votes funds for pilot plants in this session, it is expected that sufficient experience and data will be accumulated over the next 6 - 7 years to permit construction of plants producing about 250 x 10^6 ft^3 of methane per day.

If one accepts the technical feasibility of coal gasification, then one is faced with the difference in cost between natural and manufactured gas. In 1965, the "as burned" price was 26.7¢/10^6 BTU while the projected price of coal-derived gas in 1975 will be no less than 40¢/10^6 BTU (Table 31). Natural gas prices paid by the electric utilities have increased 35.1% between 1956 and 1965[1]. Projecting this rate of increase to 1975, the cost per 10^6 BTU would be 31.1¢. The cost differential between 31¢ and 40¢ would, hopefully, be closed by effecting technological economies in coal gasification. However, it should be pointed out that this differential of 32% differs very little from the 29% that is the present differential between the "as burned" price of natural gas and residual oil[2].

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[1] Steam Electric Plant Factors/1965 p.88.

[2] Steam Electric Plant Factors/1965 p.47.

If gasification of coal should become technically feasible by the middle seventies - and present indications are that it will be - then the gas reserves of the United States should be measured on the basis of the coal and natural gas reserves and not of natural gas reserves alone. Since coal reserves are considered to be adequate for our domestic needs far beyond the year 2000 (Table 9 and 10), the root reason, for which the FPC felt constrained to conserve natural gas supplies by prohibiting "inferior" uses, is no longer tenable. Further, should the coal-fired fuel cell, which today appears promising, become a reality, it could substantially increase the adequacy of our domestic coal supplies as a result of its inherent high conversion efficiency (60% as opposed to the present 35%).

One need not wait until technology is fully proven and in large scale operation but rather it is suggested that the present state-of-the-art of gasification and direct coal-energy conversion be evaluated by a high level group. Should their report suggest that gasification will become a practical reality in the near future, then natural gas conservation considerations can be immediately relegated to a secondary position by the FPC.

The second possibility, that of importing natural gas from countries such as Venezuela, has already been mentioned (Sections VII.A. and VIII.A.). The gas can be shipped by freighter (natural gas is primarily methane which is liquid between -161°

and -184° C.) in liquified form. The technology for liquification and shipment have already been worked out and regular shipments are being made between North Africa and Europe. A 50,000 ton tanker, which would be about twice the size of a conventional tanker, because the density of LNG is about half that of crude petroleum, would carry in liquid form the equivalent of about 2410 x 20^6 ft^3 of gas at 14.7 psi and 20° C. This is sufficient for about 43 days of the proposed Con Edison operation in December and January at the contract demand rate of 55 x 10^6 ft^3/day. An allowance of 1.4% gas combustion for heating the cargo to 20° C. was made. The entire annual request by Con Edison in its current proceeding before the FPC could be supplied in 9 trips by one 50,000 ton tanker.

Assuming arguendo that the price of imported natural gas delivered in New York is competitive[1] with domestic gas, the FPC would have to decide whether or not the same considerations apply to imported natural gas i.e. whether non-utility users should have a priority and, conversely, whether the use of foreign gas under industrial boilers constitutes an "inferior" use. In the opinion of this writer, the question of inferior use (of domestic gas) or what is more recently described in the TRANSCO case as "public benefit" is rooted in conservation of a national asset and consequently its optimum use. In the latter connection, pollution effects can be a major consideration. However, if domestic conservation is not a consideration, then the principal questions pertain to competition, pricing and pollution. Hence, it would seem that both the position of the FPC staff and the request of TRANSCO, Con Edison and H.E.W. could be satisfied if the domestic gas were burned in the winter months, primarily to meet space heating requirements and the imported gas were burned by Con Edison in its boilers, during that period in order to generate electricity. The question of which gas, if any, Con Edison would combust in the summer could be decided on competitive grounds since space heating requirements are non-existent.

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[1] Cost estimates by Kohn and Joyce (1966) were 25-50¢/10^6 BTU F.O.B. NY.

The importation of Venezuelan natural gas would, of necessity, result in a diminution of the importation of residual oil. It was pointed out earlier that in 1964 most of the imported residual oil burned in metropolitan New York was refined in Venezuela, Netherlands West Indies and British West Indies - 93×10^6 bbl out of 113×10^6 bbl in 1964 - and most of the crude originated in Venezuela. Hence, the economic disruption and impact on our international relations would be minimized if the case is one of substitution rather than termination of purchases.

It is suggested that a detailed analysis of Venezuelan natural gas be made from the point of view of availability, reserves, transportation costs, inter-American relations, impact on residual oil exports, storage facilities etc.

Both of the alternatives discussed above - gasification of coal and importation of LNG - would extend domestic natural gas supplies and reduce or abolish the need for their conservation; neither would be ready for large scale application before the mid-seventies. The economics and technology of both possibilities need to be evaluated thoroughly by unbiased sources, preferably outside of government, before any major policy decisions are made.

In the opinion of this author, part of the conflict in policy between H.E.W. and the FPC relating to permissible uses of natural gas stems from the lack of a high-level science adviser within the FPC. Consequently there is a sharp cleavage in attitude between health-minded H.E.W. on the one hand and rate-and-conservation-minded FPC on the other.

It is suggested that the appointment of a Science Adviser within the FPC who will have direct access to the Commissioners could have a salutary effect upon those decisions involving more than legal problems. Such an individual should have broad experience in energy resources, economics and environmental health; he should be able to identify technological areas that require further study, to stimulate the FPC or other government agencies to undertake them; he should be able to evaluate the impact of impending technological developments and interpret them to the Commission; and he should serve as the nexus between the FPC and the science community on the one hand, and other government departments with overlapping resource and technological interests on the other. This author is aware that such a recommendation falls beyond the purview of this study and none is made in the attached list of recommendations. However, the need for such an individual seems so obvious that comment is made here for informational purposes.

VIII.E. Coal Policies

The price of coal is set by the usual competitive forces acting in the market-place without any direct controls by government. However, a number of forces act indirectly in order to keep this fuel competitive or to avoid over-production. The state of Pennsylvania controls the production rate of anthracite within its borders through a state appointed committee; the latter notifies each anthracite mine owner of his production limit or quota every two weeks. This procedure has worked relatively successfully since its inception in 1939[1].

Considerable indirect influence is exerted on the coal industry by the Interstate Commerce Commission since it is responsible for regulating the rates charged interstate carriers such as oil pipelines, railroads, motor carriers, and domestic water carriers carrying natural gas[2]. The railroads have been

[1] Public Law 111, May 10, 1939, amended 1941 and 1945, State of Pa.

[2] 24 Statute 379.

under increasing pressure over the years due to competition from its two prime competitors in moving coal: the trucking and barge industries. Thus in 1933 railroads carried about 88% of the coal while in 1966 it was down to about 70%[1]. The railroads have responded to this competition by use of the "unit train," the development of "whopper-hoppers" and reductions in freight rates. Unit trains are high-speed express trains that carry coal from mine to consumer only; whopper-hoppers, as the name implies, will carry of the order of 200 tons of coal per car - an increase of a factor of two over most hopper cars today. These cars are in an advanced stage of development.

In general, it has been the policy of the ICC to permit rate reductions provided (1) the carrier was adequately reimbursed and (2) the rates were neither unfair nor destructive of competition[2]. Consequently, present rate schedules for the transportation of coal represent a mixture of improvisations which depend upon the competitive factors in each situation.

One way in which coal can remain competitive is to eliminate transportation costs of the fuel altogether. This is being accomplished by the construction of mine-mouth plants in Pennsylvania, West Virginia, Illinois, Arizona, New Mexico, and Utah. Such a development is made attractive by the use of EHV transmission lines as discussed in the section titled "Extra-High Voltage Transmission and Interties." A benefit of considerable proportions derived from such an arrangement is that the mines and, consequently, the power plants are generally not situated in densely populated areas. The combination of the remoteness of the plants and the fact that they are new or recently constructed and, therefore, usually have some of the most advanced particulate removal equipment as well as very high stacks, makes this development a desirable if temporary abatement arrangement. The ideal situation would, of course, either remove SO_2 and other effluvia from the stack gases or would remove undesirable substances before combustion.

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[1] Minerals Yearbook, Bureau of Mines, 1964.

[2] An illustrative case:
311 ICC 280, Petroleum Products from Portland, Maine to New Hampshire.

The sum of federal, state, and local laws is an indication of the intensity of interest in pollution. It is clear that where interstate pollution problems exist, the initiative on the part of the Department of H.E.W. is providing leadership in abatement. One of the initial steps in this direction was the Proposed Rule Making titled "Prevention, Control and Abatement of Air Pollution From Federal Government Activities." Although it applies to Federal facilities in a limited number of cities, it is generally regarded as the opening gun in a campaign to reduce emissions from industry in general[1]. If such a regulation were to be applied to industry or the electrical utilities in New York City it would effectively prohibit the use of coal: 0.35 lbs. of SO_2 per 10^6 BTU corresponds to 0.22% sulfur. Similarly the 0.65 lbs. of sulfur for 10^6 BTU proposed for Chicago and Philadelphia corresponds to 0.42% sulfur in coal.

Rohrman (April 1965) has tabulated the average sulfur content of coal produced by states as well as the distribution of coal consumed in power plants by percentages. Although there may be individual mines producing coal with exceptionally low sulfur content, the lowest average value was that in anthracite coal originating in Pennsylvania (0.60%). Alternatively stated, in 1963 only 4.9% of the total production of 202 x 10^6 tons had a sulfur content of 0.4 - 0.7%.

Obviously, if it is government policy to reduce SO_2 emissions in large urban centers like those identified, then the choices with respect to coal are:

(a) substitution by low sulfur fuels such as distilled (low-S) fuel oil, selected residual oil or gas.

(b) reduction of the sulfur in coal by thermal, physical or chemical means.

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[1] See bill S.780 which contains President Johnson's proposal that H.E.W. be given authority to limit emissions of pollutants by industry.

(c) removal of SO_x from stack gases.

(d) relocation of boilers to less contaminated areas.

(e) more effective dispersal in the atmosphere.

(b) and (c) are under investigation, but are not yet practical; as added capacity is needed or obsolete stations are discarded, (d) is taking place in the electrical utility industry, which used about 50% of the coal in 1965, but the replacement rate - in large part by nuclear power - of central stations is slow, since the average life of a generating station is about 40 years. Options (a) and (e) represent the least costly alternatives and the trend is toward the utilization of these two possibilities either individually or in combination in those plants that are not yet obsolete. Con Edison of New York City is in the process of finding a temporary solution: it has been scouring world-wide for sources of low sulfur residual oil. Recent reports indicate that they may have found a source in Nigeria but the adequacy of the supply is not yet clear.

In view of the absence of an accepted means of de-polluting coal or removing pollutants from the combustion products, replacement of some coal by natural gas in the highly contaminated areas would seem logical - at least on a temporary basis until the technology and economics of coal de-pollution can be solved. However, the current posture of the FPC does not make such a course seem realistic at this time; other alternatives will have to be explored and implemented[1].

It is concluded that although government policy has affected coal and therefore electrical costs for many years via its control over transportation costs, impending pressures directed at abatement of air pollution, particularly SO_x, will inevitably result in changes in quantities and kinds of coal consumed as well as the location of many new coal-burning plants away from urban centers.

VIII.F. Extra-High Voltage Transmission and Interties

Electrical power generators, as substantial consumers of fossil fuels, contribute significant amounts of pollutants to the atmosphere (Tables 4 and 25). Any process or system which optimizes the utilization of existing electrical capacity makes a contribution to pollution control by more evenly distributing atmospheric emissions. This advantage, it should be pointed out, is partially compensated by reduced costs in comparison with those rates that would obtain if new facilities had to be constructed to meet the demand; this, in turn, makes electrical energy more competitive as a power source. It is difficult, if not impossible, to sort out the individual effects of each factor with reference to the net upward trend in per capita electrical energy consumption (Table 37).

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[1] For an indication of a possible change in philosophy with respect to inferior uses of natural gas see FPC Opinion No. 516, March 1, 1967, in re the Florida Gas Transmission Corp.

Table 37

Per Capita Electrical Energy Consumption in the U.S.: 1951 - 65

Year	Kw-hr/cap.
1951	2840
1955	3853
1960	4718
1965	5969

Two major developments that have effected significant economies by permitting the exchange of large blocks of power between systems or the economical transmission of power from remote areas: extra high voltage* (EHV) transmission and inter-ties between major power systems. Inter-ties not only permit exchange of peak loads in either direction but also provide for at least partial continuity of service during major power failures. Inter-ties in particular have been fostered by the FPC as a matter of national policy.

The only EHV line in the United States until the early '50's was the one installed between Hoover Dam and Los Angeles in the '20's. Starting with the 345 KV line in the American Power System in the West Virginia-Ohio area, the use of this voltage has increased so that today there are 4 - 5000 miles in use or under construction. It is known that the Russians have been experimenting with 750 KV and that the Canadians have a 370 mile 735 KV line. Also American Electric Power has under construction a 1050 mile 765 KV line which will cost $208 million. When completed the system will link power plants in five of the seven states served by the company's subsidiaries - all coal users. Table 38 summarizes the data on EHV lines in the United States as of 1964.

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* Any power line operating higher than 230 KV is classed as EHV.

Table 38

Circuit Miles of HV and EHV Lines in the United States as of June 1965*

KV:	138	161	230	287	345	500
miles:	43,391	16,235	30,346	1023	6173	343

* Statistical Yearbook of the Electric Utility Industry for 1965, Edison Electric Institute.

The impetus behind the development of EHV transmission has not been anti-pollution considerations but the fact that higher voltages result in reduced transmission costs - making long distance transmission of large blocks of power economically feasible. The economy derives from the fact that although the increase in capital cost roughly parallels the increase in voltage, the load capacity increases as the square of the voltage. This relationship is brought out in Table 39.

Table 39

Relative Capital Cost and Capacity of EHV Lines

KV	Relative Capital Cost	Relative Load Capacity
230	1	1
345	1-1/3	2-3/4
500	1-2/3	6
700	2-1/2	13-1/2

One indication of the more efficient utilization of installed capacity and distribution is the reduced cost per unit of electrical energy in spite of inflationary trends in the general economy (Table 40).

Table 40

Average Revenue Per Kw-h*

Year	1951	1955	1960	1965
Revenue (cents/Kw-h)	1.78	1.67	1.69	1.59

* Statistical Yearbook of the Electric Utility Industry for 1965, Edison Electric Institute, Table 455.

The advantages (and disadvantages) of EHV are brought out further by Figure III. This figure brings out that (1) for a given distance the higher voltage line is more economical than a lower voltage line only above critical power demands at the receiving end (2) the cost per unit energy for a specific distance is a minimum within certain power demand ranges and (3) one can deliver energy at higher voltages over longer distances at the same price per unit energy as lower voltages over shorter distances i.e. 150 MW @ 230 KV over 200 miles of lines costs the same per Hw-h as 600 MW @ 500 KV delivered to a distribution point 600 miles away.

As a consequence of the use of EHV lines, it has been possible to tie the United States and parts of Canada into a giant network. However, the smaller segments of this network have worked more successfully than has, for example, the attempted tie between the western net having about 45×10^6 KW capacity with the eastern net having about 200×10^6 KW capacity. Starting in 1959, a tie between the east and west was attempted but "came apart" after about five minutes because of technical difficulties. Subsequent attempts lasted as long as two hours; on February 7, 1967 a successful test tie-in was announced; it has held together but judgment should be reserved until it has stood the test of at least one year of operation. As of this date three tie points between east and west are extant:

	Direction of Power Flow			
	East		West	
Location	No.	KV	No.	KV
Ft. Pack, Montana	one one	215 230	one	161
Yellow Tail Dam, Montana	one	230	many	161 & 230
Stegall, Nebraska	one	230	one	230

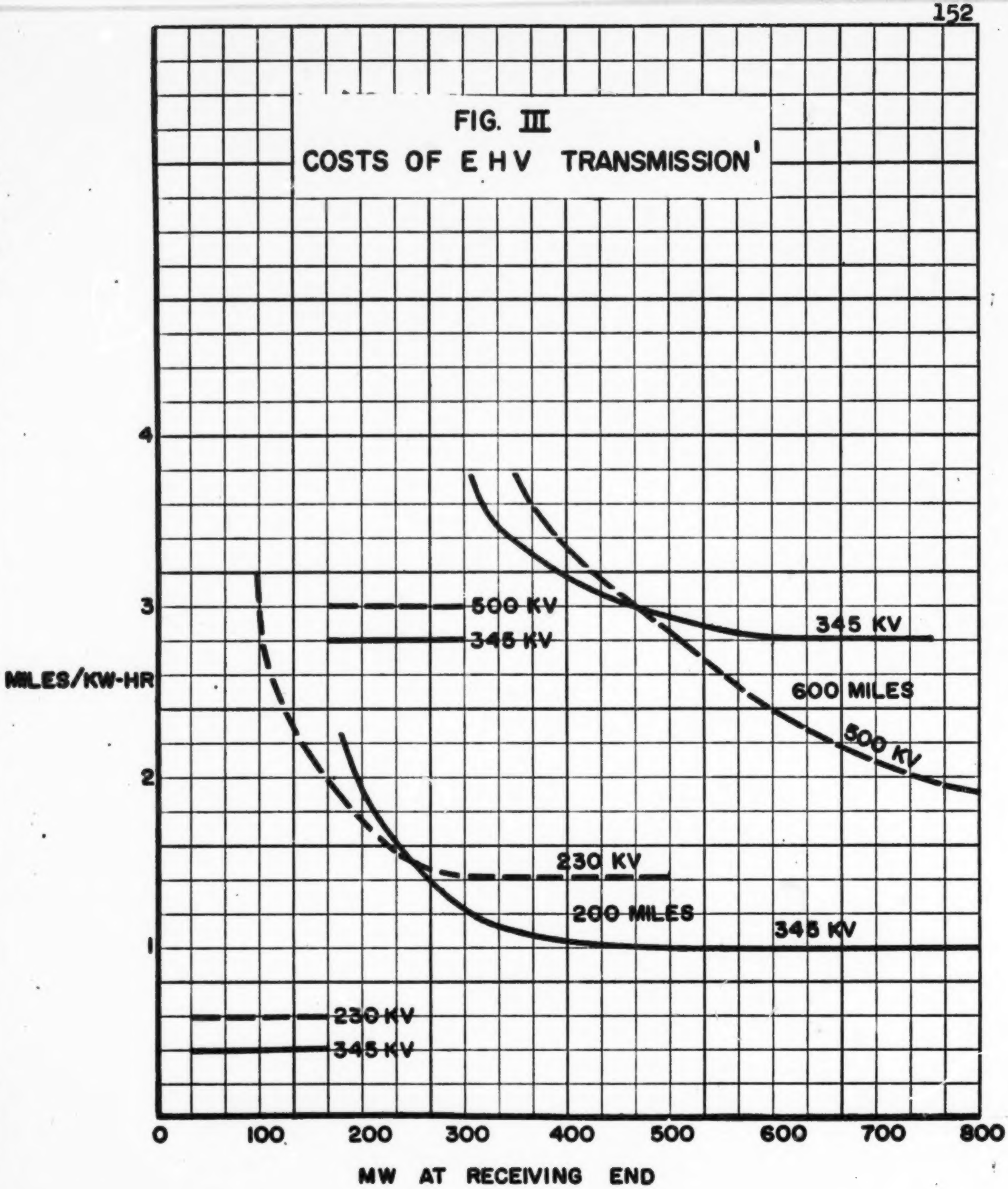

FIG. III
COSTS OF E H V TRANSMISSION'

'FROM NAT. POWER SURVEY, 1964, P.152

K•E 4 X 4 TO THE INCH KEUFFEL & ESSER CO. 358-1 MADE IN U.S.A.

In addition to increased interdependability, EHV has also made it economically feasible to place fossil fuel generating stations in remote places so as to minimize the number of people exposed to pollution as it has made feasible the transmission of power from remote hydro plants. Thus the Mojave plant on the Colorado will burn coal from Arizona and will transmit substantial quantities of its power to Los Angeles, a distance of about 300 miles, as will the "Four-Corners" Plant located at the junction of Arizona, New Mexico, Colorado and Idaho.

VIII.G. Hydropower

Hydropower is the "cleanest" of the electrical energy generating sources; it has been the policy of the Federal Government to regulate its growth for not only power generation but for conservation and flood control as well.

The original authority of the FPC dates from the Federal Water Act of 1920. This Act authorized the Commission to license non-Federal hydroelectric projects (1) located on streams over which Congress has jurisdiction and (2) those which affect public lands and reservations of the United States. In 1965 its authority over certain pumped-power was affirmed by the Supreme Court when it held that the FPC had jurisdiction over the Taum Sauk project of the Union Electric Co. even though it is located entirely within the state of Missouri. The Court held that

(1) Taum Sauk was on a stream over which Congress had jurisdiction and (2) the power generated would be transmitted in interstate commerce.

As of January 1, 1965, the potential hydroelectric resources of the U.S. were estimated to be 159.8 10^6 KW capable of producing 647.7 x 10^9 KW-h in an average year. As of that date, about 42 x 10^6 KW were in existence producing 209 x 10^9 KW-h annually[1].

As indicated by the data in Table 11, the installed capacity of hydropower is expected to grow but at a rate that is less than that of the fossil fuels. This reduced growth rate stems from the fact that as more of these plants are built, the choices are fewer and the cost per unit energy becomes less attractive.

To the extent that conventional hydroplants can be built, they eliminate the need for either fossil fuel or nuclear powered plants and thus reduce the total input to atmospheric pollution. However, the FPC has become increasingly aware of the value of these hydro-projects as a national natural resource. Consequently, the FPC has insisted that, as a prerequisite for licensing, the land and water areas under its jurisdiction be managed in such a fashion that (1) the yield of power does not significantly reduce the water yield and (2) the area associated with the

[1] Federal Power Commission, Annual Report 1965, p.75.

hydropower facility be restored so as to provide recreational facilities for the public.

One variant of hydropower is the man-made hydrosystem commonly referred to as "pumped power." In this arrangement, electrical energy is expended to pump water to a higher altitude during off-peak demand hours and electricity is regenerated from hydropower during periods of increased demand. As of January 1965 there were nine conventional pumped power projects in being or under construction with a capacity of 800 MW, an additional five "pure" pumped power projects with a combined capacity of 1,412 MW were in being or under construction[1]. Since that date, Con Edison of New York has proposed the construction of a 2,000 MW pumped power facility at Cornwall, New York and FPC hearings are currently in progress. This application for a license promises to be a landmark case for two reasons among others: (1) the pro-conservation forces are attempting to block licensing on the grounds that the area as a resource will be degraded in spite of the measures planned to avoid this possible consequence and (2) pumped power, in a total sense, increases pollutant production if it draws its off-peak power from fossil-fueled generators. The Department of H.E.W. has entered this case as an amicus curiae for the purpose of addressing itself to the pollution aspects.

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[1] The "pure" pumped-power system draws its electrical power during off-peak hours from other generating stations.

The increase in pollution products results from the fact that for every 3 KW-h expended in pumping, only 2 KW-h are recaptured in the form of electrical energy. In the case of the 2×10^3 MW Cornwall plant, the 18 x 103 MW-h or fraction thereof generated between midnight and 6 AM would have to be distributed among other power plants most of which, today, are fossil-fueled. One might also argue that pumped power increases consumption of electrical energy by obviating the necessity of building new plants thus keeping rates down. This in turn increases pollution. However, no one has ever been heard to advance the proposition that no new plants should be built as a means of reducing pollution although it should be pointed out that as new facilities are built a substantial proportion are nuclear in which case the pollution problem is readily controlled[1].

There is a fundamental pollution question involved in the Cornwall case: who and where should be exposed to the pollutants generated by power needs in areas remote from the generation facility and can sufficient anti-pollution measures be taken to satisfy those exposed, the Commission and, eventually, the Courts? Inasmuch as the case is currently before the FPC, it is expected that a decision will be forthcoming in the coming months.

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[1] See Section VI.C.

VIII.H. Internal Combustion Engines

It is well recognized - and the data in Tables 5, 14, and 15 support it - that motor vehicles are a major source of atmospheric pollutants. Current efforts to meet this problem, which constitutes government policy at federal and state levels, will undoubtedly have considerable effect upon both the quality and quantity of the fuels burned in internal combustion engines.

The combustion products consist of CO, partially and unburned hydrocarbons, NO_x and secondary products such as PAN[1]. Figure IV demonstrates the increase in use of gasoline and, therefore, of combustion products, since 1940. Its projected use, 1965 - 2000, shows a dramatic increase; this projection is realistic if (1) road construction keeps pace with car registrations (2) annual mileage driven remains constant as it has during recent years and (3) no substitute means of transportation is devised. The slope of the gasoline curve is considerably steeper than that of the population curve because the number of passenger cars per capita has increased from 0.207 in 1947 to 0.388 in 1965; at this rate of increase the latter can be expected to be 0.523 and 0.703 in 1980 and 2000 respectively; also, it is worthy of note that the gallons/vehicle-yr. have remained relatively constant in the last decade and has averaged 654 gals./vehicle.

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[1] PAN - peroxyacyl nitrates.

K+E 4 X 4 TO THE INCH KEUFFEL & ESSER CO. 358-1 MADE IN U.S.A.

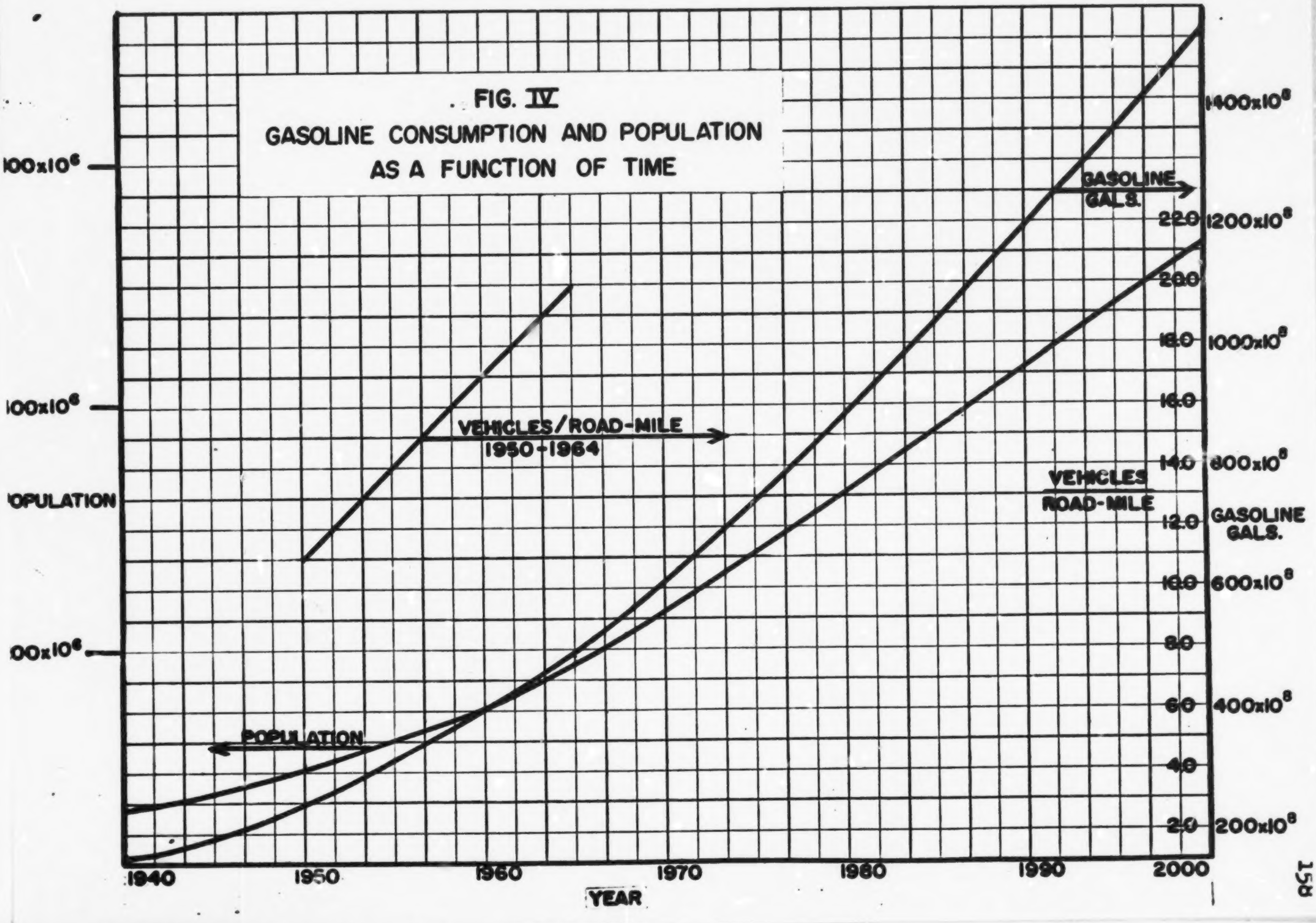

FIG. IV

GASOLINE CONSUMPTION AND POPULATION AS A FUNCTION OF TIME

At some point in the future the declining ratio of road-miles/vehicle (Figure IV) will have an impact on annual fuel consumption, thus reducing the difference in slopes between the annual gasoline consumption and population curves.

Recognition of the present and projected quantity of combustion products from the internal combustion engine and their biological and economic effects has led to intensive efforts on the part of government at all levels to devise effective counter measures. These efforts are aimed in two major directions. (1) Recognizing that the internal combustion engine will be with us in the foreseeable future, measures are being taken to improve the completeness of combustion as well as reduce noxious emissions by adsorption, catalytic oxidation or reduction, fuel additives, etc.; and (2) much research is directed at finding an acceptable substitute for the internal combustion engine. Such substitute means might include improved mass transit as well as battery, fuel cell or steam-propelled cars etc. In this connection, preliminary investigation of the combustion products of the turbine engine car suggests that hydrocarbon and CO emissions are much lower than those from a comparable reciprocating engine[1]. To the best of my knowledge, only the vehicles requiring man-power for propulsion such as the bicycle and rickshaw are not being considered as alternatives. When one takes into account the improved health of a modern society which would result from a change from a sedentary to an active modus vivendi, the latter might turn out to have the highest benefit/cost ratio.

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[1] Hearings before the Senate Subcommittee on Air and Water Pollution, 1966, p.87.

Some measure of the objectives can be gleaned from the data in Table 41. The first column presents historical data on the quantity of gasoline consumed by passenger cars; the expected consumption in 1980 and 2000 were calculated from the projected population, a projection of the 1940 - 65 increase in passenger cars per capita and the average annual consumption of gasoline per car 1955 - 65. If it is desired to reduce specific emissions to the level of any previous reference year, the composite efficiency, E_t, of all anti-emission measures that apply to each pollutant produced by internal combustion engines is given by:

$$E_t = 1 - \frac{N_o K_o (1-E_o)}{N_t K_t} \qquad (7)$$

where N_o and N_t refer to units of fuel consumed in the reference and later years respectively; gallons of gasoline/yr is used below.

K refers to the factor that applies to the conversion of fuel to a specific pollutant in the combustion chamber.

E_o is the composite removal efficiency factor in the reference year.

Table 41

Reduction Factors For Emissions From Passenger Vehicles

	Gasoline Consumed gals x 10^6	E_t (For N_o = 1940)	E_t (For N_o = 1950)	E_t (For N_o = 1960)
1940	16,759	-	-	-
1950	25,037	0.33	-	-
1955	34,319	0.51	0.27	-
1960	41,996	0.60	0.40	-
1965	49,441	0.66	0.49	0.15
1980	85,852	0.80	0.71	0.51
2000	154,020	0.89	0.84	0.73

$$E = 1 - (N_o/N_t) \text{ where}$$

N_t is the gallons consumed in any particular year.

N_o is the gallons consumed in the reference year.

E is the composite efficiency of removal for all abatement processes in cars: dimensionless.

It is assumed that no anti-pollution measures were taken in the reference year and that the factor converting fuel to pollutant is not significantly different at t or t_o.

1965 is the most recent year for which gasoline consumption data is available.

The reference years used in Table 41 are 1940, 1950 and 1960, so that $E_o = 0$. Further, it is assumed that K_o and K_t will not differ significantly when comparing any of the conversion factors in the reference years with future factors[1]. Then Equation (7) becomes

$$E_t = (1-N_o/N_t) \qquad (8)$$

where E_t applies to each pollutant.

To illustrate, if it is desired to reduce emissions of each pollutant from vehicles so that atmospheric pollution from this source is no greater in 1980 than it was in 1940, then E_t must be 0.80 (Table 41). If 1950 or 1960 are the reference years, then E_t must be 0.71 and 0.51 respectively. Present technology permits the attainment of such efficiencies for hydrocarbons and CO but not for the oxides of nitrogen.

The Clean Air Act of 1963 directed H.E.W. to develop devices and procedures for the control of automotive emissions and to cooperate with others attempting to achieve the same objectives; the amendment of 1965 authorized the Secretary of H.E.W. to establish emission limitations. These have not yet been promulgated although California requires that 1966 cars be so equipped that they meet the following standards:

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[1] This may not be strictly true after 1967 as engine designs are changed to minimize pollution.

Hydrocarbons: no more than 275 ppm by volume

CO: no more than 1.5% by volume.

It is expected that California will lower these maxima to 180 ppm and 1% by 1970. The 1966 standards were arrived at by reducing average emissions of hydrocarbons from vehicles without special abatement equipment by 80% and that of CO by 60%. The 1970 standards represent 87% and 76% reductions of hydrocarbons and CO. Reference to Table 41 indicates that in 1966 California hoped to "roll back" hydrocarbon emissions to a level existing considerably before 1940[1] while CO was expected to revert to a level close to that of 1940.

Batteries and fuel cells are the object of intensive development efforts by industry and government. During the Mercury and early Gemini flights, NASA concentrated on improving the reliability of Ni-Cd batteries and, at the same time, supported research and development on the fuel cell. While these batteries have excellent characteristics with respect to cycling, their cost is prohibitive. Industry and the military are investigating, among others, such diverse battery systems as liquid Na and liquid sulfur at 500° F (Ford), Li-Cl_2 at high temperature (General Motors), Zn-air, Zn-O_2, Li-halide and Mg-air (G.E.).

[1] This conclusion is based on an E_t = 0.66 derived from 1965 and 1940 data.

Numerous anti-pollution bills have been submitted in the 90th Congress and electric propulsion has come in for its share: Senator Magnuson would authorize up to $2 million/yr for five years for research (S. 453) while one submitted by Senator Muskie (S. 451) would authorize a total of $5 million for the same purpose.

Since one of the major thrusts of current anti-pollution efforts is to develop electric propulsion systems, it should be pointed out that if rechargeable batteries are used, these do not reduce pollution if the source of electrical energy is a fossil fuel generator. As a matter of fact, the energy requirements are roughtly the same: on the one hand, an internal combustion engine is about 8% efficient; on the other, a modern generator is 35 - 40% efficient and an electric car might have a conversion efficiency of about 25%. Thus the over-all energy utilization efficiency of both systems will be similar. However, the source of the electric power, the generator, can be located in an area which has a low atmospheric burden, thus effectively distributing the pollutants derived from fossil fuels. Of course, if the source of the electrical power were nuclear energy, the reactor would make essentially no contribution to atmospheric pollution and the use of electric vehicles could be justified, not on the basis of pollutant distribution, but of pollutant reduction.

By the year 2000, it is expected that 50% of the electric generators in this country will be nuclear. Assuming that electric vehicles have been developed to the point where they have won acceptance for intra-city travel in all congested urban districts, such as the Standard Metropolitan Statistical Areas, by the year 2000 and, further, that 50% of all travel is accomplished by this means, then it was calculated that the combustion of about 7.7×10^{10} gals. of gasoline and the generation of the associated combustion products could be avoided. Alternatively expressed, gasoline consumption would be reduced to about the 1980 level. However, 50% of this energy would be generated by fossil fuels in electric utilities[1] so that for pollution abatement purposes, there would be in fact a reduction of only 3.85×10^{10} gals. of gasoline equivalent. The remaining 3.85×10^{10} gals. would be replaced by electrical energy derived from 13.6×10^{15} BTU of heat energy (assumed 35% conversion). In this case, one would be trading gasoline derived pollutants for those derived from coal, oil and gas. Should such a situation come to pass, all electrical generating capacity estimates would have to be revised upward by a substantial amount: on the basis of the year 2000 projections in Table 26, the increase would fall into range of 22 - 37%. Further, the production of fossil fuel pollutants, as represented by the data in Tables 15 and 16, would have to be altered substantially.

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[1] The AEC has projected that by 2000 the electrical utility industry will be evenly divided between fossil fuels and nuclear fuel (see Table 26).

There has been a great deal of emphasis placed on the development of a battery operated vehicle. However, the difficulties associated with such an energy source - weight, cost, recycling limitations, short range, inconvenience etc. - the urgency of the present atmospheric pollution situation, the rate of accretion of the pollutants and the long time required for research and development, make it imperative that a number of possible countermeasures be evaluated and pursued simultaneously. Two obvious candidates are the fuel cell and mass transportation.

Fuel cell development is being funded largely by NASA; its prime contractors are the General Electric Company and Pratt and Whitney, although Allis-Chalmers, among others, have made major efforts to develop these principles into a practical device. However, as of the present, there is no directed, coherent research effort specifically directed at the development of fuel cells as an alternative to the internal combustion engine as is the case with batteries.

The responsibility for mass transportation is divided between the Department of Housing and Urban Development (mass urban travel) and the new Department of Transportation (surface mass inter-urban travel). Both urban and inter-urban transport systems can be totally electrified using conventional electric motors or any one of a number of exotic schemes. However, of the two, justification for electrification of mass urban transport on an economic and anti-pollution basis is attained with greater facility since urban travel is more of an operational than a technological problem.

In view of the implications for pollution control and abatement of operational systems such as mass transport as well as technological developments, it is suggested that it would be to the advantage of the Bureau of Disease Prevention and Environmental Health to create an office whose sole function is to maintain close liaison with other agencies such as the Departments of H.U.D., Transportation, Commerce, Defense etc., that have overlapping interests. The purpose of this office would be not only to "build bridges" but to recommend financial and administrative participation where such a course seems justified.

VIII.I. Natural Gas Pricing Policy and The Federal Power Commission

Starting March 7, 1967, representatives of the nation's producers, pipeline companies and distributors have been holding meetings in Washington among themselves and with members of the Federal Power Commission in an attempt to reach agreement on a formula for setting the price of natural gas. The prices charged for natural gas at all levels are, of course, critical in determining its availability and competitiveness with other sources of energy. From the point of view of minimizing air pollution, natural gas is the preferred fossil fuel. Therefore, the qualitative and quantitative aspects of atmospheric pollution can be radically affected by the rate situation.

The events preceding these meetings span a period of thirteen years and are so tortured that it is virtually impossible to give a detailed "blow-by-blow" account in this report. However, some of the highlights are both informative and illustrative.

The FPC is charged with responsibility for setting rates charged for natural gas sold for resale in interstate commerce; it also issues certificates authorizing construction and operation of facilities for the transportation of natural gas in interstate commerce. This authority stems from the Natural Gas Act of June 21, 1938 as amended (15 USC 717-717 W). It was in 1954 that the Supreme Court held in the Phillips Case that the FPC has authority and a responsibility to regulate natural gas prices sold in interstate commerce for resale. In a second Phillips case, the Supreme Court granted the FPC permission to set rates on a regional rather than a company-by-company basis. The country is now divided into 23 pricing areas of which the Parmian Basin in Texas and New Mexico, and the South Louisiana fields are representative.

In the case of the rate question's affecting these two regions, the one has required four years of hearings and the other five. At present, procedural questions are before the

Supreme Court for the third time. As a result of the Parmian Basin hearings the FPC has reached the decision that 16.5¢/10^3 ft^3 and 14.5¢/10^3 ft^3 from new and old wells would yield a reasonable return to the producer but on January 20, 1967 the 10th Circuit Court of Appeals in Denver ordered a rehearing in order to re-evaluate the return on investment. The FPC believes a 12% return is adequate while producers have pleaded for 16 - 18%. It is the Circuit Court of Appeals order remanding the case for further rate hearings that is now before the Supreme Court. Even if the Supreme Court permits the FPC Parmian Basin rates to stand, re-hearings will be required in order to readjust rates from the 1960 cost base to a contemporary base.

In view of the complicated and time-consuming processes involved, industry representatives have gathered (March 1967) to determine whether they can present both a united front to the FPC and, at the same time, request a rate structure that is acceptable both to industry and government.

Industry claims that the instability of the natural gas pricing system and minimal profits has resulted in reduced exploration and discovery of new gas fields. It is certainly true that the ratio of estimated natural gas reserves to annual production has shown a declining trend, viz:

Year	Ratio of Estimated Reserves to Annual Production[1]
1955	22.0
1960	20.2
1965	17.7

[1] Gas Facts, 1965, Table 5.

Whether the changing ratio is the result of lack of incentive or because new gas is more difficult to find, is another matter. In 1955, 20.8% out of 14,937 holes drilled were productive while in 1965 only 15.4% out of 9,466 holes drilled were productive. All that can be concluded from the data is that less holes are being drilled annually and that the fraction of productive ones is steadily declining.

Even if price stability should come to the natural gas industry, the above ratios of reserves to annual production are inordinately small. It would seem prudent, as a matter of national policy, to give added emphasis not only to exploration for new gas fields but also to alternative ways of extending the national natural gas reserves. Such alternatives have been previously discussed in this report (Sections VII.A. and VIII.D.) and include increased importation of liquid natural gas from non-contiguous foreign countries, importation in the gaseous form from Canada and Mexico and the gasification of coal.

VIII.J. Funding of Energy R&D

Cambel (1966) reported that energy sector sales in 1963 amounted to about $23 billion or 3.9% of the GNP and, further, that the R&D applied to energy amounted to $1 billion or 4.1% of the energy product. He is of the opinion that 4% is representative of the R&D/sales ratio in leading technical industries but that it is subatantially greater than that budgeted by typical industrial firms. The estimated break-down for the energy R&D funds for 1963[1] is as follows:

	Industry	Gov't.	Total	%
Coal	11	11	22	2.3
Oil and Gas	336	40	376	39.8
Nuclear (fission)	90	210	300	31.7
Electricity	156	1.3	157.3	16.6
Thermonuclear fusion	3	26	29	3.1
Solar, MHD, Fuel cells, Thermionics, Thermoelectrics	18.1	42.2	60.3	6.4

The data above should be regarded as only indicative since it ostensibly refers to non-defense spending but in practice it is difficult, in many cases, to separate defense from non-defense projects.

Revised data for 1966 or 1967 have not been compiled but it is informed opinion that there has been an increase which would probably keep energy R&D spending at 4% of the total energy sales and that the relative distribution is reasonably stable. It is known that for fiscal 1967, the government spending for R&D on coal has increased to $12 - 13 million and the atomic energy (fission) R&D program has risen to about $300 million. Thus, the indications are that coal R&D remains in the 2 - 3% bracket of all energy R&D although there is a small adjustment of this figure because some of the R&D listed for "Electricity" pertains to the use of coal.

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[1] Energy R and D and National Progress: Findings and Conclusions, Table III, p.13.

Cambel and his associates concluded that the allocation of the largest fraction of R&D funds to oil and gas is "consistent with current uses and anticipated requirements" (p.14). It is instructive to examine this statement more closely. Current use would hardly seem to be the only criterion for R&D allocation; other equally important considerations are resource adequacy and pollution production. However, on the basis of demand (1963) the ratio of coal to oil and gas combined (BTU) was 1:3 but the allocation of R&D funds was (1963) 1:17. Thus, on the basis of this criterion alone, coal R&D should have been increased by at least a factor of 5. On the basis of reserves, coal exceeds oil and gas combined by 4:1 hence it will be in use long after the domestic oil and gas reserves have been exhausted. Also, coal contributes at least four times more pollutants in the aggregate than natural gas (but less than petroleum products) even though the latter supplied about 30% more BTU's (1965).

Thus all the evidence is in favor of substantially increasing R&D funds for coal and applying these funds particularly to those programs that will not only make coal a more competitive fuel but also will reduce its pollutant production capacity in the process.

It is suggested that the total R&D budget for coal should be at least doubled and that the 50-50 arrangement between industry and government indicated above is equitable and should be continued.

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